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EFFECT OF SURFACE TREATMENTS ON MICROTENSILE BOND STRENGTH OF REPAIRED AGED SILORANE RESIN COMPOSITE

By

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Submitted to the Graduate Faculty of the School of Dentistry in partial fulfillment of the requirements for the Degree of Master of Science in Dentistry,

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Thesis accepted by the faculty of the Department of Prosthodontics, Indiana University School of Dentistry, in partial fulfillment of the requirements for the degree of Master of Science in Dentistry.

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INTRODUCTION

Resin composites have been widely used for several years. Currently, most commercially available resin composites have their common basis in the free radical polymerization of methacrylate. Despite significant improvement in resin composite formulations over the years, many modern systems are still based on variations of the bis-GMA molecule, which has been used for more than 30 years. One of the identifiable disadvantages of this material is high polymerization shrinkage.[1] Different researchers have shown an average of 2.0-6.0 vol% shrinkage.[2-4] Polymerization shrinkage leads to clinical problems such as microleakage, postoperative sensitivity and secondary caries.[5]

STATEMENT OF PROBLEM

To overcome polymerization shrinkage, a silorane based material was introduced. A silorane molecule is a product from the reaction of oxirane and siloxane molecules.[2,6,7] Silorane based resin composite has shown approximately 0.94 – 1.5 vol% shrinkage [2,4,8] and comparable flexural strength to methacrylate based resin composite.[2] Because of improved polymerization shrinkage, silorane resin composite may become a material of choice for direct restorations. With the clinical use of the material, minor deterioration or fractured restorations are expected. Replacement of the restorations is not always necessary and is often discouraged.[5] At present, there is no available information regarding the repair potential of silorane resin composite with the same material or with the methacrylate based resin composite. Determining the repair bond strength of new resin composite applied to aged silorane resin composite would be beneficial for the clinician.

REVIEW OF LITERATURE

Many factors affect the longevity of resin composite restorations such as patient's oral hygiene, clinician's clinical experience and age of patients.[9] Normally, resin composite restorations are replaced at a median age of 7-8 years.[9] Secondary caries and marginal discoloration are the most common reasons for replacement of resin composite restorations.[10]

Replacement of resin composite restoration has several disadvantages. It is time-consuming and additional cost is required. Gordan[10,11] reported a significant increase in the size of the cavity preparation resulting from removal of more tooth structure. The re-restoration cycle generally results in weakening of the tooth structure and subsequently in tooth loss.[9] An alternative and more conservative treatment such as repair should be considered.

Gordan et al[5] reported a two year clinical evaluation of repair versus replacement of resin composite restorations. They found that repair had significant improvement of the margins of restorations. Moreover, repair treatment showed no significant difference when compared with the replacement and remained stable over two years. They concluded that repair should be considered whenever possible.[5]

Resin composites have been used to replace missing tooth structure, modify tooth color and contour, and enhance facial esthetics. In 1955, Buonocore[12] introduced orthophosphoric acid etching technique to improve adhesion between acrylic resin and enamel.[12] Development of dental resin composites has been dominated by the use of methacrylate resins.

One of the disadvantages of resin composite is the stress associated with polymerization shrinkage. Polymerization shrinkage of methacrylate based resin composite ranges between 2-6% by volume.[3] Polymerization shrinkage of dental resin composite occurs as a result of monomer molecules are converted into a polymer network and interaction spaces change from van der Waals force dimensions to covalent bond dimensions.[8] Reduction of polymerization shrinkage has been an important issue since this polymerization shrinkage leads to microleakage, postoperative sensitivity, secondary caries and marginal staining.[5,13] Polymerization shrinkage also creates contraction stresses in the resin composite restoration and internal stress can cause deformation in the surrounding tooth structure.[14]

There have been several attempts to overcome polymerization shrinkage such as using an incremental layering technique, placing a stress absorbing liner and changing the light curing procedures.[13,15] A recent one is the use of ring opening polymerization of the silorane molecules (Figure 1, 2).[16] Silorane containing resins are being developed by 3M-ESPE.[1] Recently, Weinmann et al[2] described the synthesis of this new monomer system. Silorane is derived from the combination of oxirane and siloxane molecules.[2,6] The siloxane backbone was introduced in order to increase hydrophobicity. Hydrophobic materials are much less sensitive to exogenous staining than hydrophilic materials.[2] Increased hydrophobicity of silorane resin composite was shown to have an advantageous effect on material properties such as water sorption and solubility.[6]

Like methacrylate based resin composite, silorane resin composite (Filtek LS) consists of four main components.[2,7,17] The filler is a combination of fine quartz particles and radiopaque yttrium fluoride. The polymer matrix is silorane and the photoinitiator is camphorquinone and iodonium salt. The use of fine particular quartz contributes to good esthetic performance and mechanical stability. The quartz surface is modified with a silane layer. As it is known for the methacrylates, the silane layer increases the hydrophobic character of the surface of the filler. At the same time, the silane layer acts as the interface between filler and matrix facilitating the reinforcement of the resin with the hard filler particles. The silane layer prevents an attack of the acidic Si–OH groups of the quartz, which could potentially result in undesired initiation of the cationic polymerization process.

Polymerization

Whereas, the polymerization process of methacrylate based resin composite occurs via free radical polymerization,[18,19] the polymerization of silorane resin composite is generated by the cationic ring opening polymerization of the cycloaliphatic oxirane molecule (Figure 2).[2] The cationic polymerization starts with the initiation process of an acidic cation which opens the oxirane ring and generates a new acidic center, a carbocation. After the addition to an oxirane monomer, the epoxy ring is opened to form a chain, or in the case of bi- or multifunctional monomers a network is formed.

A three-component initiating system is made up of camphorquinone, an iodonium salt and an electron donor. Camphorquinone is used as a photoinitiator in order to match the emission spectra of the currently used dental lamps.[2,17] In this reaction path, the electron donor acts in a redox process and decomposes the iodonium salt to an acidic cation which starts the ring opening polymerization process. The three component system provides for the optimal balance between high polymerization reactivity and light stability. The silorane resin composite has two main advantages[16]: low polymerization shrinkage due to the ring opening oxirane monomer and increased hydrophobicity because of the siloxane molecules.[16]

Resin composite materials have relatively short clinical longevity. Mjör et al [9] reported that the average lifetime of resin composites is 7-8 years.[9] Recurrent caries and discoloration are the main reasons for replacement of resin composite restorations in general dental practice.[20] The other reasons include dislodgement, fracture of the tooth, and pain or discomfort leading to replacement.[20]

Total replacement is not always necessary nor desirable.[21] Replacement frequently involves the removal of additional tooth structure in order to optimize the new enamel bonding leading to a larger restoration with further loss of tooth structure.[21] Bonding between a new layer of resin composite and aged resin composite may occur by two main mechanisms; micromechanical retention and chemical bonding.[22]

There is a consensus that the bonding of new to aged resin composite is micromechanical but chemical bonding should also be taken into consideration.[22-24] When considering chemical bonding to aged methacrylate based resin composite, Padipatvuthikul and Mair[25] proposed two possible mechanisms being promoted by a bonding agent. The first mechanism is micromechanical retention created by penetration of the unfilled resin into the surface irregularities or microdefects in the aged resin composite. The second may be related to the solvents in the adhesive systems. These solvents may cause swelling and gelation of the surface layer, allowing the monomer in the layer of the repair filling access to unconverted vinyl groups (C=C) in the substrate of the filling.[25]

As resin composite continues to mature after placement, the available vinyl group (C=C) for cross-polymerization to the new resin composite layer decreases over time. This might affect the ability of new resin composite to bond to the aged resin composite. Research has shown that the repair bond strength of aged resin composite was compromised with reduced numbers of unconverted carbon double bonds and lack of an oxygen inhibiting layer.[25]

Potential for chemical bonding to the aged silorane resin composite is unclear. Whether the presence of an oxygen inhibited layer on the polymerized surface of a silorane resin composite might be an important factor for chemical bonding to aged silorane resin composite is still in question. Tezvergil-Mutluay et al[26] suggested that no oxygen inhibited layer existed at the surface of silorane resin composite because silorane undergoes cationic ring opening polymerization reactions which are not sensitive to oxygen. On the other hand, Shawkat et al[27] have found that an oxygen inhibited layer was present although with minimal thickness after polymerization of silorane resin composite. They stated that iodonium salts are effective photoinitiators of cationic polymerization and absorb short wave length ultraviolet light. However, in dental applications, a wider spectrum of light source is used. This light source might be critical for the effectiveness of cationic polymerization. During the electron-transfer photoinitiation reaction, a redox reaction occurs creating a radical and a cation-radical which generates the cationic initiating species. The presence of this radical species may react with oxygen under conventional light curing conditions and results in an oxygen inhibited layer. More researches are needed to understand the role of an oxgen inhibited layer in repair of silorane resin composite.

Several methods of surface treatment have been widely used to establish adequate bond strength between aged resin composite and new resin composite including surface hydrofluoric acid etching, sandblasting with aluminum oxide particles, abrasion with a diamond bur followed by silica coating, and the use of intermediate bonding agents.[15-16,21,28-30] Surface treatment of aged resin composite has two main purposes[30]; to remove the superficial layer altered by the saliva exposing a clean, higher energy composite surface, and to increase the surface area through creation of surface irregularities.[31]

Papacchini et al[21] compared the 24 hour microtensile bond strength of a microhybrid resin composite to the same material after different surface treatments. They found that air abrasion with aluminum oxide particles and the application of a bonding agent produced the highest microtensile bond strength, followed by a mix of hydrochloric acid and hydrofluoric acid, then a fine grit diamond bur, respectively.

Junior et al[16] investigated the microtensile bond strength of the aged microhybrid and nanohybrid resin composites treated with different surface treatments; hydrofluoric acid etching, abrasion using a coarse diamond bur, sandblasting using alumina particles and silica coating. They concluded that sandblasting with aluminum oxide particles and silica coating produced the greatest microtensile bond strength value, irrespective of primer used. They also reported that a more even surface topography was achieved using aluminium oxide sandblasting in comparison with diamond bur abrasion resulting in greater microtensile bond strength value and suggesting a more effective pattern for mechanical retention. Moreover, they also found the etched aged resin composite with hydrofluoric acid produced the lowest microtensile bond strength value.

Therefore, Junior et al [16] stated that hydrofluoric acid should be avoided for repairing aged resin composite.

In addition, Ozcan et al[30] stated that among the particle abrasion systems, aluminium oxide presents the best bond strength values compared to other methods since it provides microretention on the aged resin composite surface. Particle deposition, at the same time, increases the ability of the new resin composite to mechanically interlock to the substrate due to the increase in surface area. Moreover, these retentive surface textures favor the surface wettability that allows optimal adaptation of the resin composite.

Trajtenberg et al [31] reported the opposite result. In their study, hydrofluoric acid produced the highest tensile bond strengths when used to prepare the three laboratory resin composites. Furthermore, they also investigated the repair bond strength of a laboratory processed resin composite treated with hydrofluoric acid gels with different concentrations and etching times.[32] There was no significant difference in repair bond strength with respect to different acid concentrations or the etching times tested.[32]

There is currently no available data focusing on the effect of surface treatment on repair bond strength of aged silorane resin composite. The purposes of this in vitro study were to examine the microtensile bond strength of repaired aged silorane resin composite with different methods of surface treatment and to compare the microtensile bond strength of repaired aged silorane resin composite when repaired with silorane resin composite and with methacrylate based resin composite.

Null hypotheses:

(1) There is no difference in microtensile bond strength of repaired aged silorane resin composite when tested after different methods of surface treatment.

(2) There is no difference in microtensile bond strength of repaired aged silorane resin composite when repaired with either silorane or methacrylate based resin composite.

Alternative hypotheses:

(1) Microtensile bond strength of repaired aged silorane resin composite will vary when aged silorane resin composite is treated with different methods of surface treatment.

(2) Microtensile bond strength of repaired aged silorane resin composite is lower when repaired with the methacrylate based resin composite.

MATERIALS AND METHODS

In this laboratory study, the repaired microtensile bond strengths of aged silorane resin composite using different methods of surface treatment and either silorane or methacrylate based resin composite were compared, and the types of failure were examined using light microscopy.

Specimens:

One hundred and eight silorane resin composite blocks (Filtek LS, shade A2, 3M ESPE, St. Paul, MN, USA) with dimensions of 6 mm x 6 mm x 12 mm for the control and 6 mm x 6 mm x 6 mm for the test specimens were fabricated using a silicone mold (Figure 3). The resin blocks were built in increments of 2 mm using a plastic instrument. Each layer was cured for 40 seconds using a Demetron LC curing unit (Kerr, Orange, CA USA) with the intensity of 600 mW/cm^2.[33] Tip of light curing unit was kept perpendicular to and in contact with Mylar strip in order to receive a maximum curing depth. The intensity of the LED curing light was monitored with a Cure Rite Visible Curing Light Meter (Dentsply, York, PA, USA). The top of each specimen was covered with a Mylar strip in order to obtain a flat surface and to aid in removal of excess material. All specimens were polished using 240, 320, 400 and 600 silicon carbide paper including the top surface in order to remove the excess of resin composite and to make the surface perpendicular to the specimen's long axis. All specimens were cleaned in tap water for 10 minutes in an ultrasonic device to remove loose particles and stored in distilled water for 24 hours.

Aging method:

After polishing and storing in distilled water for 24 hours, all specimens were aged by thermocycling (5000 cycles, 8°C to 48°C, dwell time: 30 s, transfer time of 10 s).

Surface treatment procedures:

The surface treatment procedure was performed 2 days after thermocycling was done (because of the weekend) and on the same day of repairing. Silorane resin composite blocks with dimensions of 6 mm x 6 mm x 12 mm were used as a control. All remaining resin composite blocks with dimensions of 6 mm x 6 mm x 6 mm were randomly assigned into four groups. Surface treatment procedure was performed as described below:

Control group:

Solid silorane resin composite blocks were used as controls. This was done to determine the actual cohesive strength of the silorane resin composite.

Group 1: no surface treatment

Specimens received no surface treatment of the aged resin composite.

Group 2: acid treatment

The aged specimen surfaces were etched with 35% phosphoric acid gel (Scotchbond, 3M ESPE, St. Paul, MN, USA) for 15 seconds for the group that was repaired with methacrylate based resin composite (group 2M). The aged specimen surfaces were etched with LS System self etch primer (LS System adhesive, 3M ESPE, St. Paul, MN, USA) for 15 seconds for the group that was repaired with silorane resin composite (group 2S). Then, all specimens were rinsed with water and excess water was removed with canned compressed oil-free air (Falcon Dust off Air Duster, Branchburg, NJ, USA).

Group 3: sandblasting with aluminum oxide (AO)

Each resin composite specimen was abraded for 10 seconds with a distance approximately 10 mm perpendicular to the resin composite block using an intraoral air abrasion unit (Microetcher II, Danville Engineering INC., San Ramon, CA, USA) using 50 μm aluminum oxide particles (Danville Engineering INC., San Ramon, CA, USA) with an air pressure of 60 psi. All specimens were rinsed with water and then excess water was removed with canned compressed oil-free air.

Group 4: abrasion with a coarse diamond bur

The aged specimen surfaces were roughened with a coarse-grit diamond bur for 10 seconds (No. 027, Brasseler, Savannah, GA, USA). A high speed handpiece with a water spray was used. The pressure equivalent to a mass of approximately 4.0 ± 1.0 g was used.[34] Before the roughening procedure, the operator was trained on the surface of an analytical balance (AE 100, Mettler-Toledo, Inc, Columbus, OH, USA) to determine the equivalent manual pressure that was placed on the surface of the resin composite. Then, the specimens were rinsed with water and then excess water was removed with canned compressed oil-free air.

Application of adhesives and resin composites:

After surface treatment, all specimens in each group except the control group were randomly assigned into 2 subgroups.

The first subgroup (1S, 2S, 3S, 4S) was repaired with new silorane resin composite (Filtek LS, Shade C2, 3M ESPE, St. Paul, MN, USA) using LS System adhesive (3M ESPE, St. Paul, MN, USA). The second subgroup (1M, 2M, 3M, 4M) was restored with methacrylate based resin composite (Filtek Z250, Shade A4, 3M ESPE, St. Paul, MN, USA) using the fifth generation one-bottle dentin adhesive agent (Adper™ Single Bond Plus, 3M ESPE, St. Paul, MN, USA). All adhesive systems were applied and polymerized on all aged resin composite specimens as described below.

LS System adhesive:

After the surface treatment procedure, the LS System adhesive self etch primer was applied on the surface treated resin composite for 15 seconds except for group 1S (no surface treatment group) and group 2S (acid etching group) because group 2S was previously etched from the surface treatment. Then, all etched specimens were gently dried with canned compressed oil-free air and 10 seconds of light cure (Demetron LC curing unit, Kerr, Orange, CA, USA). Then, LS adhesive bonding was applied on the surface of all resin composites (including group 1S, 2S), followed by gentle air drying and 10 seconds of light cure.

Adper™ Single Bond Plus System adhesive:

After the surface treatment procedure, 35% phosphoric acid gel (Scotchbond™ Etchant, 3M ESPE, St. Paul, MN, USA) was applied to the surface treated resin composite for 15 seconds except for group 1M (no surface treatment group) and group 2M (acid etching group) because group 2M was previously etched from the surface treatment. Then, the etched resin composites were rinsed for 10 seconds. Excess water was removed with canned compressed oil-free air. Then, Adper™ Single Bond Plus adhesive agent (3M ESPE, St. Paul, MN, USA) was applied in 3 consecutive coats for 15 seconds on the surface of all resin composites (including group 1M, 2M) with gentle agitation using a fully saturated applicator, followed by air drying for 5 seconds to evaporate the solvent and 10 seconds of light cure.

Then, a new layer of resin composite was applied to the aged silorane resin composite with the aid of a silicone mold. Each increment was packed with a clean plastic instrument and light cured for 40 seconds. After repairing, all specimens were stored in 37 ºC distilled water for 24 hours.

Microtensile bond strength test: [16,21,34]

After storing in 37 ºC distilled water for 24 hours, the resin composite blocks were cut using a slow speed water-cooled saw equipped with a diamond impregnated disk (Isomet, Buehler, Lake Bluff, IL, USA) at a speed of 300 rpm, producing 9 beams with an average area of 0.64 mm^2 (0.8 mm x 0.8 mm) for each beam (Figure 4, 5). The beams located at the periphery of block were discarded.

After storing in 37 ºC distilled water for 24 hours, the beams were attached to the holder of a universal testing machine (MTS Sintech Renew 1123, Eden Prairie, MN, USA). All beams were loaded in tension until fracture at a crosshead speed of 1 mm/min (Figure 5, 12).

A pilot study was done using this method to determine if solid silorane specimens could be used as a control group. The results indicated that the solid specimens could break in the gap between the upper and the lower jig of the Universal testing machine.

Failure analysis:

Fracture surfaces of the repaired groups were examined using optical microscopy at 20X magnification. The type of failure was determined to be either *adhesive failure* (between aged and new repaired resin composites involving the intermediate layer); *cohesive failure* (within the aged or repairing resin composite); or *mixed* (combination of adhesive failure and cohesive failure).

Statistical analysis:

Comparisons between the groups for differences in microtensile bond strength were performed using a Weibull-distribution survival analysis, using the force required for failure in place of the usual ‘time to event’ seen in typical survival analyses. The analysis included a “frailty” term to correlate the measurements from beams coming from the same specimen. Specimens which failed before placement on the testing machine were accommodated in the survival analysis model as left-censored observations, and specimens which did not fail prior to the end of testing were accommodated as right-censored observations. Differences between the groups for type of failure were analyzed using generalized estimating equation methodology applied to cumulative logistic regression models.

Sample size justification:

Although the analyses were performed using survival analysis, the sample size calculations based on the t-test provided appropriate estimates. Based on the studies by Junior[16] and Pappacchini[21], the standard deviation of the microtensile bond strengths was expected to be approximately 20 MPa. Based on a prior study by Eckert and Platt[35], within-specimen correlation among beams was approximately 0.3. With a sample size of 12 specimens per group and 9 beams per specimen, the study had an 80% power to detect a difference of 15 MPa between two groups, assuming a two-sided 5% significance level for each comparison.

RESULTS

<u>Microtensile bond strength</u>

When compared to the control group, the microtensile bond strength ranged from 50.2 ± 1.6 MPa or 80.19% of cohesive strength for the group 3S to 37.2 ± 1.6 MPa or 59.42% of cohesive strength for the group 1S. The second highest microtensile bond strength was group 3M (47.8±1.5 MPa or 76.36% of cohesive strength), followed by group 2M (44.1±1.8 MPa or 70.45% of cohesive strength), group 1M (40.8 ±1.9 MPa or 65.18% of cohesive strength), group 4S (39.0±1.7 MPa or 62.30% of cohesive strength), group 4M (37.7±1.6 MPa or 60.22% of cohesive strength), group 2S (37.3±2.0 MPa or 59.58% of cohesive strength), respectively. The lowest microtensile bond strength presented in group 1S (37.2±1.6 MPa) or 59.42% of cohesive strength (Table 3, 4 and Figure 6).

After evaluation of the results using Weibull-distribution survival analysis (Table 3, Figure 7), it showed that group 1M, 1S, 2S, 4M, and 4S had significantly lower microtensile bond strength than the control with p-values of 0.03, 0.006, 0.008, 0.007 and 0.01 respectively. Thus, microtensile bond strength was marginally lower on group 2M than the control group (p=0.07). Moreover, microtensile bond strength of group 3S and 3M was not significantly different from the control (p>0.05). No other statistically significant differences were found among other groups.

The lowest microtensile bond strength was presented in the no surface treatment group which was repaired with silorane resin composite (group 1S). The highest microtensile bond strength was observed in the sandblasting surface treatment group irrespective of the material used. In addition, although this result showed that group 2M, 3S and 3M produced microtensile bond strength as high as the cohesive strength of silorane resin composite, the repair bond strength was still lower than the cohesive strength of silorane resin composite.

Type of failures

As shown in Table 5, in the majority of tested beams, fractures developed at the resin composite-resin composite interface (81%), followed by cohesive failure (18%) and mixed failure (1%), respectively. Group 4S showed the highest adhesive failure (94%), followed by group 4M (88%), group 1S (87%), group 2M (82%), group 2S (80%), group 1M (77%), respectively. Surface treatment with sandblasting showed the lowest percent of adhesive failure (63% for group 3M and 72% for group 3S).

Conversely, the highest percent of cohesive failure was found in the sandblasting groups (36% for group 3S and 24 % for group 3M). The lowest percent of cohesive failure presented in the surface treatment with abrasion with diamond bur (6% for group 4S, 4M). The cohesive failure of remaining groups was 13% (group 1S), 18% (group 2M), 19% (group 2S) and 22% (group 1M). Mixed failure was also found in group 4M (6%), group 3S (2%), group 3M (1%) and group 2S (1%). There were only 3 beams that did not break during the testing because of glue separation (Table 5).

In addition, statistical analysis showed that group 4S had a significantly higher proportion of adhesive failure than group 1M, group 2M, group 2S, group 3S, and group 3M with p-values of 0.004, 0.015, 0.009, 0.001 and 0.001, respectively. Group 4M had a significantly higher proportion of adhesive failure than group 3S ($p = 0.006$) and group 3M ($p = 0.001$). Group 1S had a significantly higher proportion of adhesive failure than group 3S ($p = 0.007$) and group 3M ($p = 0.001$). Group 3M had a significantly lower proportion of adhesive failure than group 2M ($p = 0.001$) and group 2S ($p = 0.018$) (Table 6).

FIGURES

Figure 1: Silorane molecule[2]

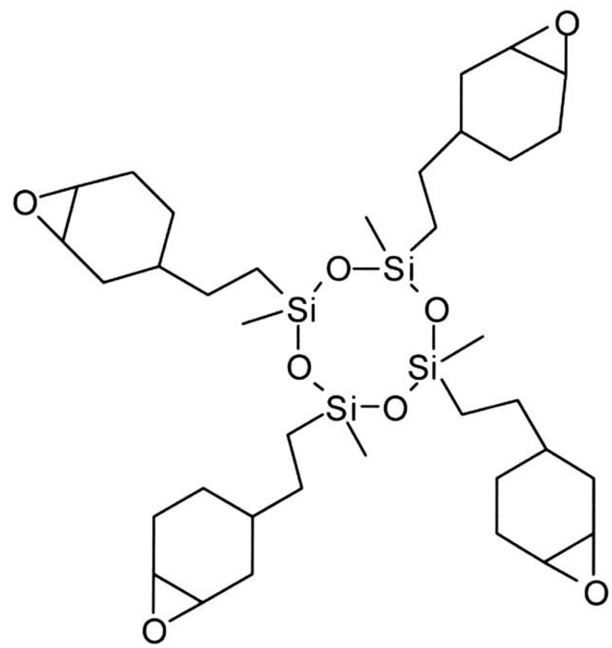


Figure 2: Ring opening polymerization of silorane resin composite[2]

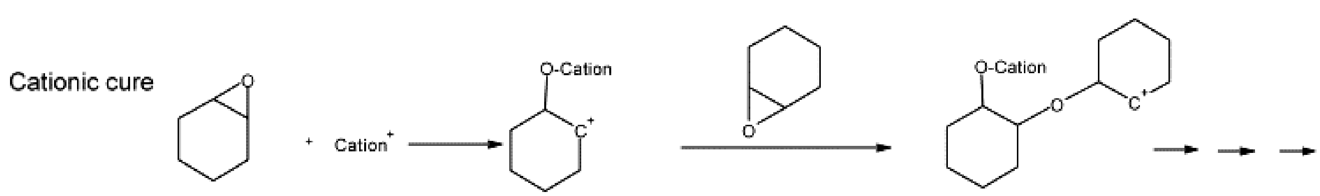


Figure 3: Experimental groups

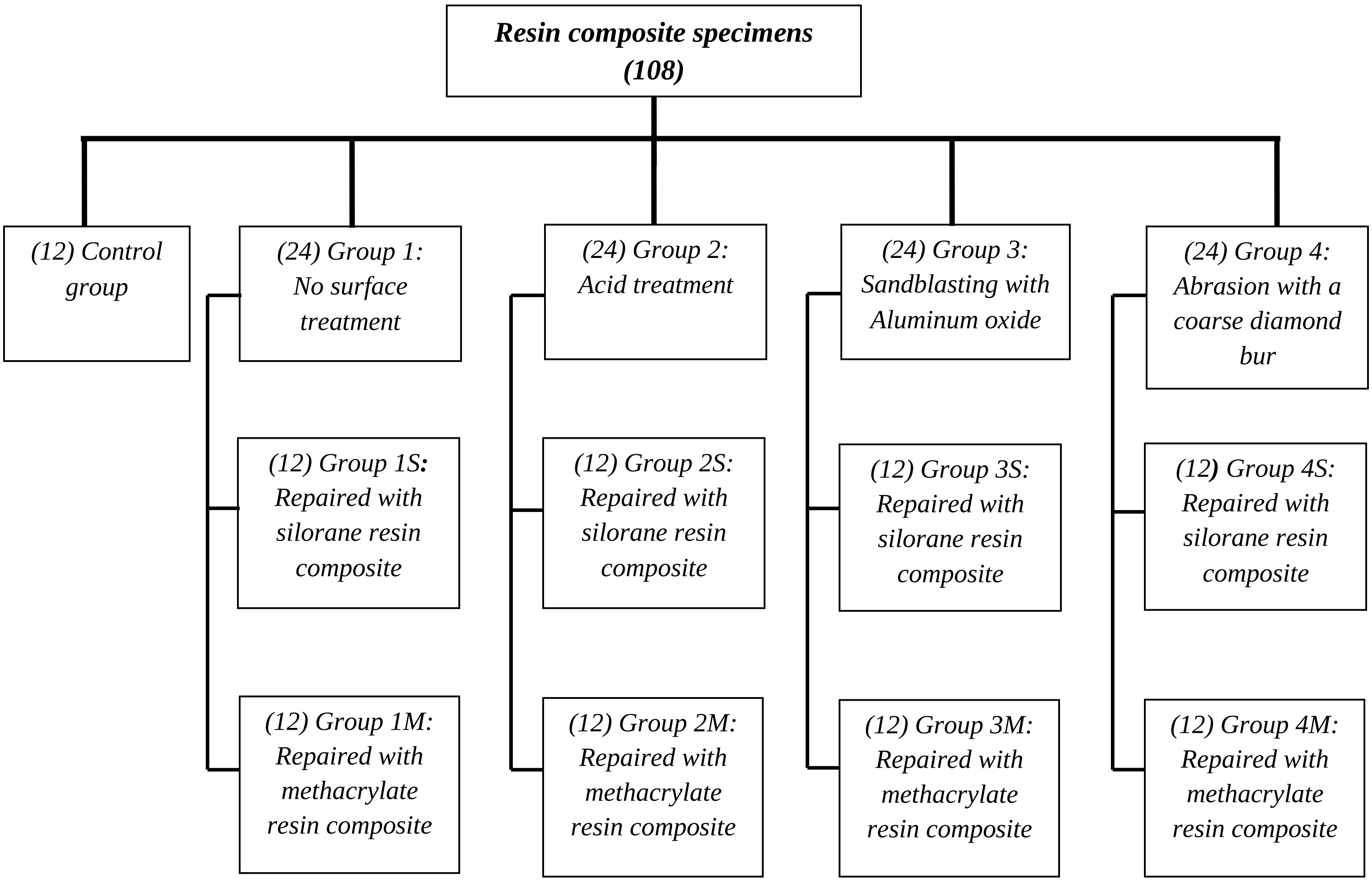


Figure 4: Control and tested specimens

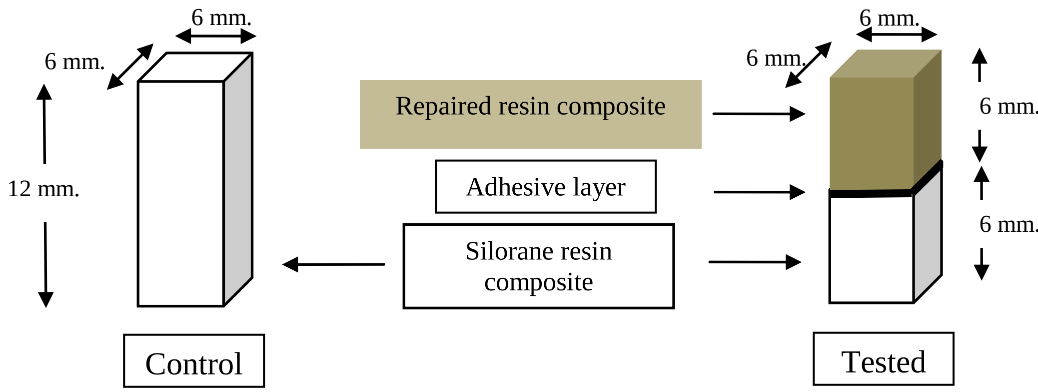


Figure 5: Non-trimming microtensile bond strength test

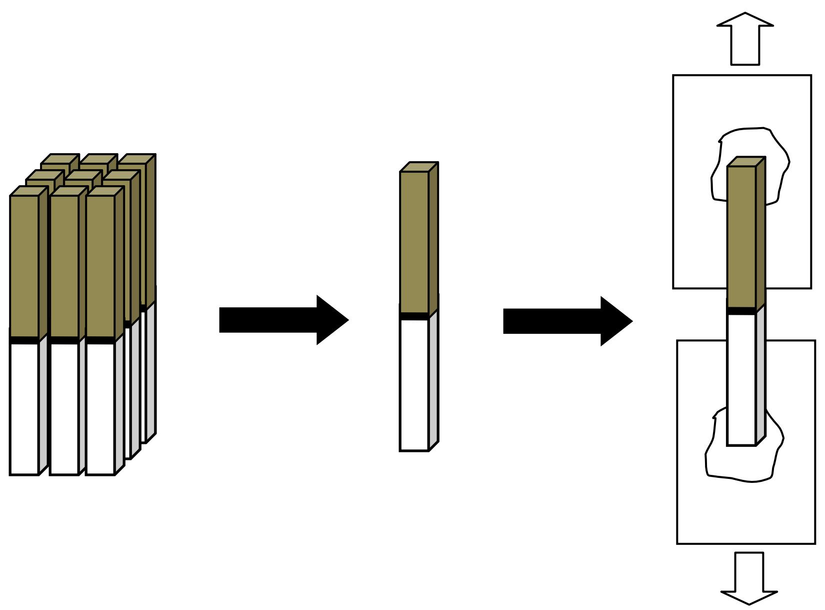


Figure 6: Mean and standard deviation of experimental groups

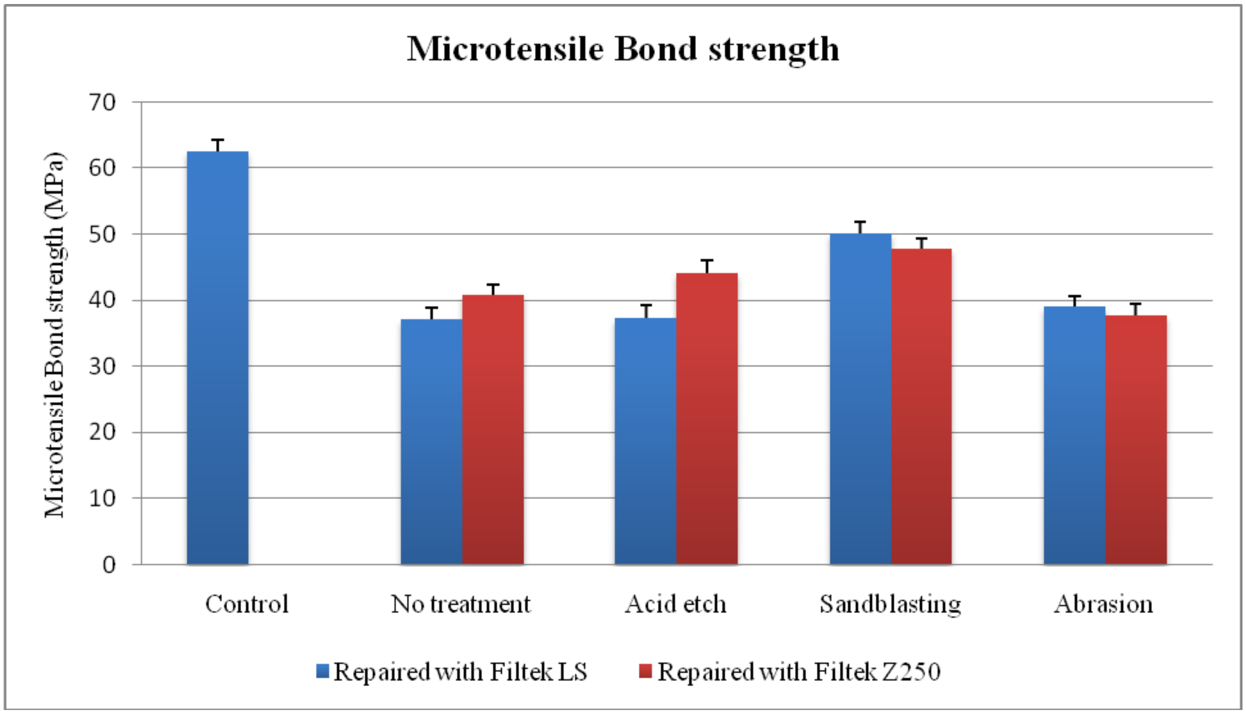


Figure 7: The survival probability of failure fitted by the Weibull model

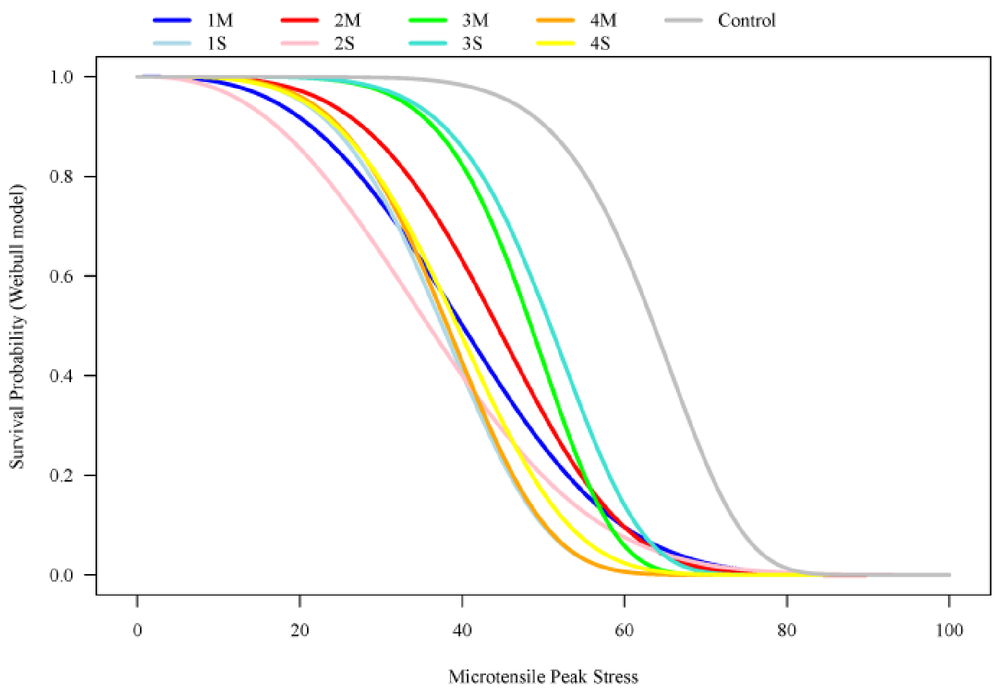


Figure 8: An intraoral air abrasion unit (Microetcher II, Danville Engineering INC., San Ramon, CA, USA)

Figure 9: Low speed cutting machine (Isomet, Buehler, Lake Bluff, IL, USA)

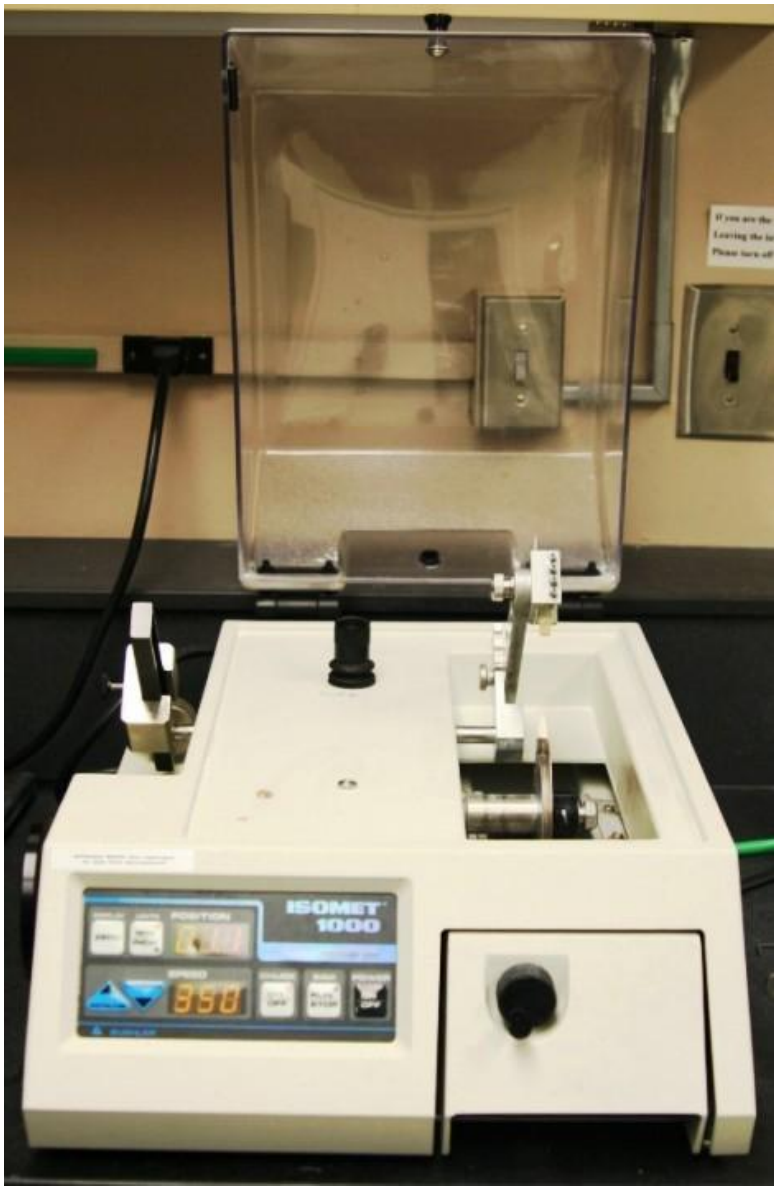


Figure 10: Resin composite beam before microtensile testing

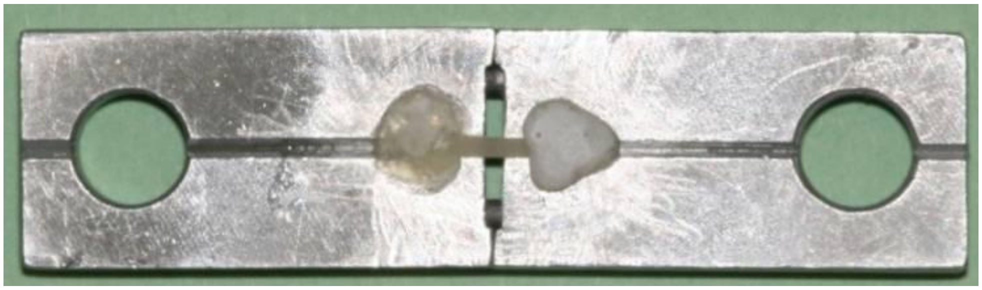


Figure 11: Fractured resin composite beam after microtensile testing

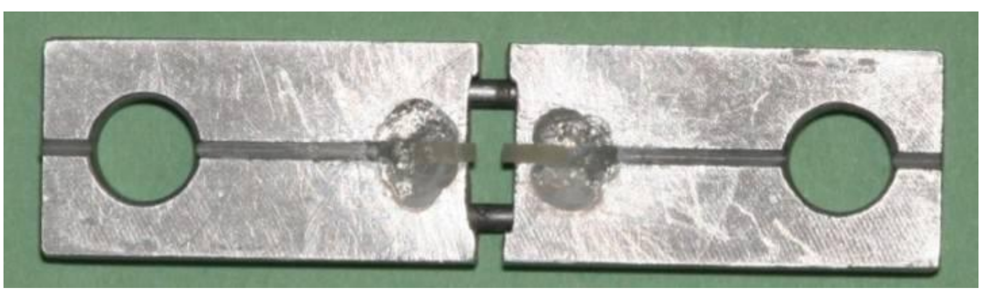
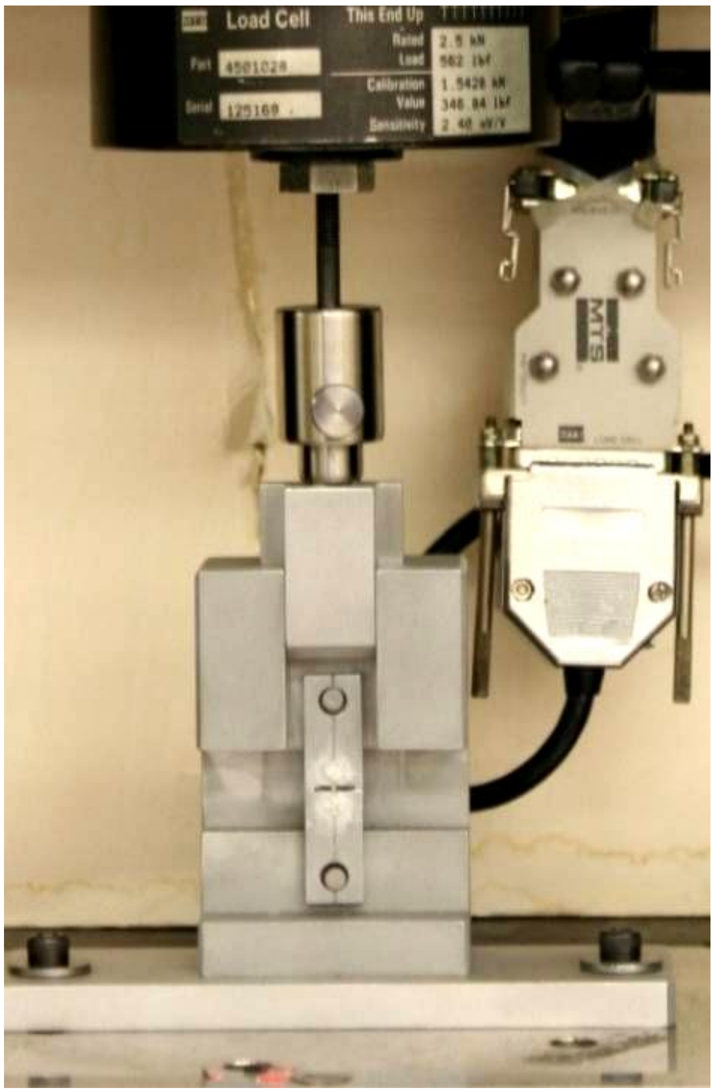


Figure 12: Mounted specimen on the Universal Testing Machine before testing (MTS Sintech Renew 1123, Eden Prairie, MN, USA).



TABLES

Table 1: Experimental groups

Group	Surface Treatment	Bonding Procedure
Control	–	–
1S	No surface treatment	LS adhesive bonding
1M	No surface treatment	Single Bond application
2S	LS System self etch primer	LS adhesive bonding
2M	35% Phosphoric acid etching	Single Bond application
3S	Sandblasting with aluminum oxide	LS System self etch primer + LS adhesive bonding
3M	Sandblasting with aluminum oxide	35% Phosphoric acid + Single Bond application
4S	Abrasion with Diamond bur	LS System self etch primer + LS adhesive bonding
4M	Abrasion with Diamond bur	35% Phosphoric acid + Single Bond application

Control = Solid silorane resin composite blocks (Filtek LS)
S = The silorane resin composite (Filtek LS) blocks were repaired with silorane resin composite (Filtek LS)
M = The silorane resin composite (Filtek LS) blocks were repaired with methacrylate based resin composite (Filtek Z250)

Table 2: Materials, batch number, type and general compositions

Materials	Batch No.	Type	General composition
Filtek LS (3M ESPE)	N18197	Micro-hybrid	***Filler:*** Silanized quartz, yttrium fluoride 76 wt% ***Resin matrix:*** 3,4-Epoxycyclohexylethyl-cyclopolymethylsiloxane, Bis-3,4-epoxycyclohexylethylphenylmethyl-silane
Filtek Z250 (3M ESPE)	N163688	Micro-hybrid	***Filler:*** Zirconia/silica 85 wt% ***Resin matrix:*** Bis-GMA (bisphenol A diglycidyl ether diemthacrylate) and a blend of UDMA (urethane dimethacrylate) and Bis-EMA (bisphenol A polyethylene glycol diether dimethacrylate)
LS System adhesive (3M ESPE)	N157377	Self-etch Primer & bond	***Self etch primer:*** Phosphorylated methacrylates, Vitrebond copolymer, Bis-GMA, HEMA (2-hydroxyethyl methacrylate), water, ethanol, camphorquinone and silane treated silica filler, initiators, stabilizers ***Bond:*** Hydrophobic methacrylate, phosphorylated methacrylate, TEGDMA (triethylene glycol dimethacrylate), silane treated silica filler, initiators, stabilizers, camphorquinone
Adper™ Single Bond Plus System adhesive (3M ESPE)	393173	Total etch & bond	***Etchant:*** 35% phosphoric acid ***Bond:*** Bis-GMA, HEMA, dimethacrylates, ethanol, water, photoinitiator system, methacrylate functional copolymer of polyacrylic and polyitaconic acids, silica particles

Table 3: Mean, percent of cohesive strength and p-value of experimental groups

Surface treatment	**Repair Materials**	**Groups**	**Mean Bond strength (MPa)**	**Percent of cohesive strength**	**p-value**
Control		Control	62.6 $\pm$ 1.6	100	-
No treatment	Filtek LS	1S	37.2 $\pm$ 1.6	59.42	0.006*
	Filtek Z250	1M	40.8 $\pm$ 1.9	65.18	0.030*
Acid etch	Filtek LS	2S	37.3 $\pm$ 2.0	59.58	0.008*
	Filtek Z250	2M	44.1 $\pm$ 1.8	70.45	0.070
Sandblast	Filtek LS	3S	50.2 $\pm$ 1.6	80.19	0.230
	Filtek Z250	3M	47.8 $\pm$ 1.5	76.36	0.130
Abrasion	Filtek LS	4S	39.0 $\pm$ 1.7	62.30	0.014*
	Filtek Z250	4M	37.7 $\pm$ 1.6	60.22	0.007*

**statistically significant difference ($P<0.05$) when compared to the control*

There was no other statistically significant difference among other groups.

Table 4: Descriptive statistics of experimental groups

Group	Microtensile bond strength (MPa)				Weibull Characteristic Strength	Weibull Modulus
	Min	Max	Mean	SE		
Control	38.7	90.6	62.6	1.6	66.7	8.0
1S	13.1	66.8	37.2	1.6	41.0	4.2
1M	0.5	73.9	40.8	1.9	45.3	3.0
2S	3.8	73.1	37.3	2.0	41.5	2.6
2M	10.6	77.5	44.1	1.8	48.6	4.0
3S	18.0	90.0	50.2	1.6	54.0	6.3
3M	17.6	64.9	47.8	1.5	51.3	6.6
4S	11.9	64.3	39.0	1.7	43.2	4.0
4M	14.4	59.3	37.7	1.6	41.6	4.4

Table 5: Statistical comparison of microtensile bond strength

Comparison	p-value
1M & 1S	0.58
1M & 2M	0.69
1M & 2S	0.63
1M & 3M	0.48
1M & 3S	0.33
1M & 4M	0.63
1M & 4S	0.79
1M < Control	0.030*
1S & 2M	0.34
1S & 2S	0.96
1S & 3M	0.21
1S & 3S	0.12
1S & 4M	0.94
1S & 4S	0.77
1S < Control	0.006*
2M & 2S	0.38
2M & 3M	0.76
2M & 3S	0.55
2M & 4M	0.38
2M & 4S	0.51
2M & Control	0.07*
2S & 3M	0.24
2S & 3S	0.14
2S & 4M	0.99
2S & 4S	0.82
2S < Control	0.008*
3M & 3S	0.77
3M & 4M	0.23
3M & 4S	0.33
3M & Control	0.13
3S & 4M	0.14
3S & 4S	0.21
3S & Control	0.23
4M & 4S	0.83
4M < Control	0.007*
4S < Control	0.014*

* statistically significant difference

Table 6: The incidence of failure mode (N, %)

Group	Adhesive	Mixed	Cohesive	Did not break
1S	94 (87%)		14 (13%)	
1M	83 (77%)		24 (22%)	1 (1%)
2S	86 (80%)	1 (1%)	21 (19%)	
2M	89 (82%)		19 (18%)	
3S	78 (72%)	2 (2%)	26 (24%)	2 (2%)
3M	68 (63%)	1 (1%)	39 (36%)	
4S	102 (94%)		6 (6%)	
4M	95 (88%)	6 (6%)	7 (6)%	
Total	695 (81%)	10 (1%)	156 (18%)	3 (0%)

Table 7: Statistical comparison of type of failure

Comparison	**p-value**
1M & 1S	0.10
1M & 2M.	0.39
1M & 2S	0.71
1M & 3M	0.06
1M & 3S	0.52
1M & 4M	0.08
1M < 4S	0.004*
1S & 2M	0.33
1S & 2S	0.20
1S > 3M	0.001*
1S > 3S	0.007*
1S & 4M	0.84
1S & 4S	0.09
2M & 2S	0.65
2M > 3M	0.001*
2M & 3S	0.07
2M & 4M	0.27
2M < 4S	0.015*
2S > 3M	0.018*
2S & 3S	0.28
2S & 4M	0.16
2S < 4S	0.009*
3M & 3S	0.11
3M < 4M	0.001*
3M < 4S	0.001*
3S < 4M	0.006*
3S < 4S	0.001*
4M & 4S	0.13

* statistically significant difference

DISCUSSION

The objective of this study was to compare the repaired microtensile bond strength of aged silorane resin composite using different surface treatments and either silorane or methacrylate based resin composite.

Microtensile bond strength testing was suggested by Sano et al.[36] They found that there was an inverse relationship between tensile bond strength and bonded surface area. Smaller bonded surface area is associated with higher tensile bond strength which is adhesive failure in nature[30], whereas larger bonded surface area showed lower tensile bond strength because of the presence of more defects/stress raisers at the interface or substrate in the larger specimens. Moreover, microtensile bond strength testing often results in higher bond strengths at failure than are found using larger specimens such as shear or tensile bond strength testing. Microtensile bond strength was chosen in the present study because the purpose of this experiment was to compare the repair bond strength which is at the interface between aged and a new repair resin composite. The bond strength values from microtensile bond strength testing are normally from adhesive failure, so the bond strength value will be the adhesive bond strength instead of cohesive strength from cohesive failure. In the present study, the microscopic study showed most failures resulted from adhesive failures. As approximately 81% of bond strength values were resulted from adhesive failure, it can be assumed that the bond strength values would be representing adhesive bond strength rather than cohesive bond strength. A concern was raised regarding internal flaws and microcracks within specimen beams. The serial cuts in order to obtain beams for testing might create internal flaws within the beams.[37] In this study, the speed of the diamond saw was constant. In this way, the same internal flaws within the beams were created.

At present, clinically sufficient repair bond strength is not known. Several studies have shown that the surface treatments of aged resin composite significantly affected the bond strength of newly repaired resin composite. Generally, the microtensile bond strength of resin composite to dentin ranges between 25.8-48.0 MPa.[38,39] For enamel bonding, the microtensile bond strength of resin composite normally ranges between 33.8-55.6 MPa.[40] It is well known that resin composite seldom fails mechanically at the junction with etched enamel. Therefore, it can be surmised that a repair bond strength which is similar to that of resin composite to etched enamel would be clinically adequate.[41]

Surface treatment

In the present study, silorane resin composite was repaired with either silorane resin composite or methacrylate based resin composite because in a clinical situation the clinician may have no information about the chemical composition of the existing resin composite. Repairing existing silorane restoration is critical because there is limited information regarding repair protocol of silorane resin composite.

In this study, microtensile bond strength of repaired aged silorane resin composite without any surface treatment (group 1S, 1M) was significantly lower than the cohesive strength of silorane resin composite (control group) indicating a weak repair bond strength. This might be because of the lack of surface irregularities from surface treatments. This result is in accordance with Luhrs et al’s study.[42] In their study, microtensile bond strength of aged silorane resin composite when repaired with the same material using only bonding was significantly lower than those from the solid specimens (control).

A question arises in this study because the microtensile bond strength in the no surface treatment group (group 1M, 1S) was approximately the same as or even higher than the repair bond strength in abrasion with diamond bur group (no significant difference). This might be because of the following possible reasons.

Other than micromechanical retention, the chemical bonding on aged silorane resin composite to either silorane or methacrylate based resin composite is still unknown. But both mechanical and chemical bonding might be considered. First, polishing the top surface of the resin composite blocks with sandpapers infused with aluminum oxide particles prior to aging procedure might create surface roughness for further bonding. Furthermore, micromechanical retention might also come from penetration of the unfilled resin into the microdefect in the aged resin composite as described by Padipatvuthikul and Mair. [25] Second, unreacted sites and the use of adhesive bonding might be considered. The solvent in both the silorane and methacrylate adhesive bonding might cause swelling and gelation of the surface layer[25] allowing the monomer in the layer of the repair filling access to the unreacted functional group of the silorane. Third, this might be from an insufficient aging process. The cycles may not have been sufficient to create hydrolytic degradation on the resin composite surface so that the repair bond strength might have come from the remaining reactivity of the material.

In the acid treatment group, when compared to the control group, the use of 35% phosphoric acid presented marginally significant lower microtensile bond strength when the silorane resin composite was repaired with the methacrylate based resin composite (group 2M). In addition, for the group 2S, etching the aged silorane resin composite with the self etching primer in the LS system adhesive produced significantly lower microtensile bond strength than the cohesive strength of silorane resin composite (control). The results of the present study agree with Luhrs et al's study.[42] In their study, silorane resin composite (Filtek Silorane) was repaired with different surface treatment protocols. It was found that the use of only silorane bonding (group 1S in this study) and the use of silorane self etch primer and bonding (group 2S in this study) showed significantly lower microtensile bond strength compared to the solid silorane specimens (control). And also, there was no difference between the use of only silorane bonding (group 1S in this study) and the use of silorane self etch primer and bonding (group 2S in this study). Therefore, the microtensile bond strength of the repaired specimens did not benefit from the additional use of silorane self etching primer.

This is in accordance with other studies[15,16,21,43,44] because etching the aged resin composite surface with 37% phosphoric acid or self etch primer showed virtually no increase in repair bond strength compared to no surface treatment. Cavalcanti et al[43] reported that 35% phosphoric acid and self etch primer used to treat the aged resin composite surface demonstrated no significant influence on the repair bond strength. Thus, in their study[43], the microtensile bond strength was significantly lower than ultimate tensile strength of resin composite. Similarly, another study[44] showed no increase in repair bond strength when the resin composite was prepared with 37% phosphoric acid.

According to Duarte et al[45], etching dentin with phosphoric acid before the application of LS system self etch adhesive (primer and bonding) showed an increase of mean microtensile bond strength values compared to those of the silorane adhesive applied according to the manufacturer's instruction. Therefore, it may require additional phosphoric acid cleaning prior to application of LS self etch adhesive in order to increase the repair bond strength of aged silorane resin composite. But the literature has contradictory information regarding the surface treatment with acid etching because surface treatment with phosphoric acid is normally unable to increase repair bond strength of aged resin composite regardless of the use of an additional phosphoric acid cleaning step. In addition, Cavalcanti et al[43] stated that the additional phosphoric acid cleaning seems to be an irrelevant procedure when self etching systems are used for resin composite repair because they found that the phosphoric acid cleaning procedure prior to the use of self etching system showed no significant influence on repair bond strength.

In the sandblasting with aluminum oxide particles group, the results of this study indicated that surface treatment using sandblasting with aluminum oxide particles is an effective surface treatment procedure for the repair of resin composite restorations. Either silorane resin composite specimens repaired with silorane resin composite (group 3S) or repaired with methacrylate based resin composite (group 3M) showed no significant difference in microtensile bond strength compared to the cohesive strength of silorane resin composite (control). This result indicates that surface treatment with aluminum oxide particles provides comparable microtensile bond strength to the solid silorane specimens. Air abrasion with aluminum oxide particles is the surface treatment that causes microretentive features.[43] Although this study did not used scanning electron microscopy (SEM) to examine the surface topography, some authors have reported this information confirming high surface roughness with aluminum oxide sandblasting.[26,34] Costa et al[34] found that aluminum oxide sandblasting produced the significantly highest surface roughness compared to no surface treatment and roughening with a diamond bur. And this might be the reason why aluminum oxide sandblasting produced the highest repair bond strength compared to other groups. Furthermore, a more irregular surface topography was achieved using aluminum oxide sandblasting in comparison with abrasion with a diamond bur producing a more effective pattern for mechanical retention and resulting in greater microtensile bond strength values.[16]

Ozcan et al[30] stated that surface treatment using sandblasting with aluminum oxide particles presented the highest repair bond strength. They also proposed that this is because aluminum oxide sandblasting provides microretention on the aged resin composite surface. Deposition of the particles increases the ability of the new resin composite to mechanically interlock due to the increase in surface area. In addition, these retentive features favor the surface wettability of the resin composite allowing for optimal adaptation.

In the abrasion group, the use of a diamond bur on the aged silorane resin composite showed significantly weaker in repair bond strength than the cohesive strength of silorane resin composite (control group) regardless of the use of either silorane resin composite (group 4S) or methacrylate based resin composite (group 4M). The effect of surface abrasion with a diamond bur on the repair bond strength of aged resin composite is debated due to some studies not showing significantly improved repair bond strength while others did. Thus, this technique provides a less predictable outcome compared to sandblasting with aluminum oxide particles.

Lloyd et al [46] found no difference between the repair bond strength of five chemically cured resin composites when the surface was ground or when it was not. Moreover, some authors have reported the reduction in repair bond strength after surface abrasion with a diamond bur. They proposed this reduction of bond strength due to the exposure of filler particles following surface abrasion and consequently decreased availability for primary bonding to the resin composite. Other possibilities are debris interference with the repair potential and the inclusion of air at the interface reducing the surface area available for bonding.[41]

In contrast, some studies have shown that surface abrasion with a diamond bur significantly improved the repair bond strength of resin composite specimens. This might be because of an increase in the surface area for micromechanical retention following abrasion. Crumpler et al[47] concluded that surface roughness enhances the ability of new resin composite to mechanically interlock with the aged resin composite as an increased surface area available for bonding. Furthermore, Shahdad et al[41] concluded that surface abrasion of a fractured resin composite surface produced a significant increase in repair bond strength.

Repair materials

Even though this study did not try to bond silorane resin composite using methacrylate based dentin adhesive (Adper™ Single Bond Plus System adhesive), Duarte et al[45] found that there was no adhesion of Filtek LS applied directly over dentin surface treated with Adper™ Single Bond Plus. They reported that the total etch methacrylate based dentin adhesive was not able to produce sufficient bond strength to hold silorane resin composite on the dentin. Most of specimens spontaneously debonded after 24 hours and all remaining restorations debonded after water storage or thermocycling.

In the present study, surface of aged silorane resin composite was prepared and restored with either silorane resin composite with LS system self etch adhesive or methacrylate based resin composite with Adper™ Single Bond Plus system adhesive. No spontaneous debonding was found. The repair microtensile bond strength (37.2-50.2 MPa) was in the same range as the bond strength of resin composite to enamel (33.8-55.6 MPa[40]). Moreover, the repair microtensile bond strength in group 3M and group 3S was comparable to the cohesive strength of silorane resin composite (80.19% and 76.36% of cohesive strength respectively). This might indicate that when the surface of silorane resin composite is prepared with aluminum oxide sandblasting, it can be repaired with either silorane resin composite with the LS system self etch adhesive or methacrylate based resin composite using a methacrylate based dentin adhesive.

A recent study[26] showed that it is possible to bond methacrylate based resin composite to the silorane resin composite using a phosphate methacrylate intermediate resin (Silorane System Adhesive Bond) which was not performed in this study. In their study, they found an increase in shear bond strength between silorane resin composite (Filtek LS) and methacrylate based resin composite (Filtek Z250) using phosphate dimethacrylate based intermediate resin compared to the use of a dimethacrylate based intermediate resin (Adper Scotchbond Multipurpose Adhesive). Phosphate dimethacrylate based intermediate resin is based on methacrylate chemistry with phosphate group. The possible reaction of the phosphate group with oxirane and the acrylate group with dimethacrylate might be the reason. Although, this study did not use phosphate dimethacrylate intermediate with methacrylate based resin composite, their study is still unclear because silorane resin composite was a fresh bonding (no aging condition) so that greater reactivity of the material need to be taken into consideration. Further research on repairing aged silorane with phosphate dimethacrylate should be done.

It was interesting to see quite different results from the two subgroups that were etched prior to bonding. When repaired with Filtek Z250, the acid etch with 35% phosphoric acid was able to produce the microtensile bond strength values that were not significantly different from the cohesive strength values of the silorane resin composite. For the subgroup that was etched with LS self etch primer and repaired with Filtek LS, the repaired microtensile bond strength was significantly lower than that of the cohesive strength of the material. Results from subgroups 1M and 1S were interesting as well. Group 1M seemed to produce better microtensile bond strength than group 1S, even though values were not significantly different. Group 1M also resulted in higher numbers of cohesive failures, which suggested higher success in bonding of the two materials at their interfaces. From these results, methacrylate based resin composite seemed to be a better choice of repair material in the situation that the air abrasion unit was unavailable. Although the bonding between methacrylate based resin composite to the aged silorane resin composite without surface treatment mechanically is unknown, the chemical bonding was likely responsible for this increase in microtensile bond strength between the methacrylate base resin composite to the aged silorane resin composite (group no surface treatment and acid treatment) .

Failure mode

In this study, 81% of repaired specimens failed adhesively, 18% failed cohesively and 1% failed mixedly. For the majority of failures, therefore, the weak link was the adhesive interface. Moreover, groups that presented with approximately equal microtensile bond strength did not always fail in the same manner such as groups 1M and 4S. The microtensile bond strength of group 1M and 4S was 40.8 MPa and 39.0 MPa, respectively. Although, both group 1M and 4S presented closely similar repair bond strength, group 4S showed significantly higher adhesive failures than those of group 1M. Furthermore, in the groups that presented the highest microtensile bond strengths (group 3M, 3S) showed more cohesive failures than other groups.

The different results between subgroups within the same group (2S and 2M) suggested strongly that not only micromechanical retention was responsible for the repair. The chemical bonding was another factor that could not be overlooked, since it was capable of producing significantly different repair microtensile bond strength values. With either abrasion with a diamond bur or abrasion with air abrasion unit with aluminum oxide particles, silorane resin composite seemed to work better. Without any surface treatment mechanically, the chemical bonding between the methacrylate based resin composite and aged silorane resin composite produced better results than using its own type as a repair material. The chemical reaction between the methacrylate based resin composite to the aged silorane resin composite must be further explored to explain these results.

For the further research, determining the surface roughness of each surface treatment using SEM analysis or profilometry, using an intermediate agent such as a silane containing agent, using a phosphate dimethacrylate intermediate layer and clarifying the chemical bonding mechanism between silorane resin composite to either silorane or methacrylate based resin composite would give more information regarding the repair protocol for aged silorane resin composite.

SUMMARY AND CONCLUSIONS

The purpose of this study was to compare the repaired microtensile bond strength of aged silorane resin composite using different surface treatments and either silorane or methacrylate based resin composite. Silorane resin composite blocks (Filtek LS) were fabricated and aged by thermocycling between 8^{o}C and 48^{o}C (5000 cycles). A control (solid resin composite) and four surface treatment groups (no treatment, acid treatment, aluminum oxide sandblasting and diamond bur abrasion) were tested. Each treatment group was randomly divided in half and repaired with either silorane resin composite (LS adhesive) or methacrylate based resin composite (Filtek Z250/Single Bond Plus). After 24 hours in 37^{o}C distilled water, microtensile bond strength testing was performed using a non-trimming technique. Fracture surfaces were examined using an optical microscope (20X) to determine failure mode.

Weibull-distribution survival analysis revealed that aluminum oxide sandblasting followed by silorane or methacrylate based resin composite and acid treatment with methacrylate based resin composite provided insignificant differences from the control ($p>0.05$). All other groups were significantly lower than the control. Failure was primarily adhesive in all groups. In general, aluminum oxide sandblasting produces the most desirable repair bond strength of aged resin composite. The result of this study agrees with the above statement regardless of whether the silorane or methacrylate based resin composite used. The conclusions that can be drawn from this study are:

1. Surface treatment on aged silorane resin composite using air abrasion with aluminum oxide particles resulted in microtensile bond strength values that were slightly lower, but were not significantly different from those resulted from cohesive strength of the silorane resin composite.

2. After treating the resin composite surface with aluminum oxide sandblasting, aged silorane resin composite can be repaired with either silorane resin composite with LS system adhesive or methacrylate based resin composite with methacrylate based dentin adhesive.

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APPENDICES

Table 1: Data from control group: Solid silorane resin composite

Block	Beam	Peak Load	Peak Stress	Strain	Modulus
1	1	44.110	68.9	0.002	42888.474
1	2	33.051	51.6	0.001	45665.262
1	3	36.371	56.8	0.001	47166.405
1	4	40.729	63.6	0.002	32725.321
1	5	41.997	65.6	0.002	37055.080
1	6	43.034	67.2	0.002	35998.002
1	7	50.590	79.0	0.002	40245.157
1	8	44.342	69.3	0.002	42352.001
1	9	52.084	81.4	0.003	31687.162
2	1	51.120	79.9	0.003	27665.535
2	2	48.212	75.3	0.003	28924.627
2	3	45.735	71.5	0.002	37285.449
2	4	37.329	58.3	0.003	31425.466
2	5	45.808	71.6	0.003	30264.547
2	6	46.114	72.1	0.003	29933.280
2	7	39.442	61.1	0.003	25992.834
2	8	43.571	68.1	0.003	28846.675
2	9	50.342	78.7	0.004	32251.707
3	1	24.952	39.0	0.001	27886.638
3	2	33.390	52.2	0.002	31792.798
3	3	45.185	70.6	0.003	30238.247
3	4	25.991	40.6	0.001	30635.440
3	5	42.664	66.7	0.002	29561.342
3	6	41.389	64.7	0.002	34411.408
3	7	30.624	47.8	0.001	39352.262
3	8	43.992	68.7	0.002	33496.506
3	9	33.972	53.1	0.002	29181.355
4	1	44.880	70.1	0.002	35833.075
4	2	35.062	54.8	0.002	35872.464
4	3	47.530	74.3	0.002	36132.267
4	4	36.549	57.1	0.002	32124.756
4	5	47.404	74.1	0.002	34858.751
4	6	34.858	54.5	0.003	24490.437
4	7	46.352	72.4	0.002	36122.400
4	8	33.116	51.8	0.002	31316.785
4	9	38.449	60.1	0.003	34038.751

Table 2: Data from control group: Solid silorane resin composite (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus
5	1	31.650	49.5	0.002	33751.118
5	2	38.917	60.8	0.002	42477.946
5	3	43.043	67.3	0.001	50323.172
5	4	39.670	62.0	0.001	45774.126
5	5	29.470	46.0	0.001	42507.966
5	6	39.078	61.1	0.002	44746.663
5	7	45.726	71.4	0.003	42557.656
5	8	24.756	38.7	0.001	37697.766
5	9	46.101	72.0	0.002	44555.287
6	1	49.345	77.1	0.003	34268.021
6	2	27.791	43.4	0.001	37279.549
6	3	44.415	69.4	0.002	38617.817
6	4	35.421	55.3	0.002	41466.255
6	5	48.995	76.5	0.002	35979.879
6	6	43.793	68.4	0.002	35429.963
6	7	44.183	69.0	0.002	40280.838
6	8	41.249	64.5	0.002	31940.104
6	9	57.979	90.6	0.003	36446.476
7	1	39.854	62.3	0.002	35007.932
7	2	45.564	71.2	0.002	36030.007
7	3	39.223	61.3	0.002	35679.394
7	4	29.467	46.0	0.001	40877.813
7	5	36.697	57.8	0.001	39541.026
7	6	44.223	69.1	0.002	60327.492
7	7	34.649	54.1	0.001	44216.644
7	8	40.050	62.6	0.001	44223.310
7	9	33.070	51.7	0.001	46414.137
8	1	45.828	71.6	0.002	37686.793
8	2	36.923	57.7	0.001	43535.344
8	3	44.703	69.8	0.002	37966.985
8	4	38.592	60.3	0.002	29728.297
8	5	38.104	59.5	0.002	40645.777
8	6	32.596	50.9	0.001	37815.747
8	7	51.073	79.8	0.002	37493.717
8	8	46.035	71.9	0.002	43064.373
8	9	51.079	79.8	0.002	36746.766

Table 3: Data from control group: Solid silorane resin composite (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus
9	1	36.314	56.7	0.002	34223.153
9	2	43.709	68.3	0.002	32006.865
9	3	44.963	70.3	0.003	35248.526
9	4	31.986	50.0	0.002	36105.448
9	5	40.060	62.6	0.002	42475.322
9	6	29.835	46.6	0.003	30781.298
9	7	36.498	57.0	0.003	36488.951
9	8	41.673	65.1	0.002	37455.748
9	9	39.723	62.1	0.002	45527.248
10	1	37.864	59.2	0.002	43450.248
10	2	36.701	57.3	0.002	40322.097
10	3	36.346	56.8	0.002	48368.482
10	4	39.791	62.2	0.003	39746.752
10	5	29.626	46.3	0.001	35451.888
10	6	39.913	62.4	0.003	44314.799
10	7	28.570	44.6	0.002	25527.999
10	8	37.171	58.1	0.002	37862.715
10	9	44.420	69.4	0.002	35104.126
11	1	47.956	74.9	0.002	42559.144
11	2	34.926	54.6	0.002	41610.193
11	3	42.967	67.1	0.002	35159.319
11	4	46.427	72.5	0.002	40625.874
11	5	29.549	46.2	0.001	42748.355
11	6	27.932	43.6	0.001	33449.401
11	7	28.175	44.0	0.001	33863.420
11	8	39.382	61.5	0.002	33739.934
11	9	48.679	76.1	0.003	35670.452
12	1	45.055	70.4	0.003	40787.272
12	2	43.965	68.7	0.002	42265.612
12	3	39.721	62.1	0.002	36028.364
12	4	43.737	68.3	0.002	48576.747
12	5	37.052	57.9	0.001	45511.795
12	6	43.114	67.4	0.002	44230.834
12	7	39.506	61.7	0.002	43364.658
12	8	37.333	58.3	0.002	30692.069
12	9	39.388	61.5	0.002	39200.566

Table 4: Data from group 1S: Silorane resin composite repaired with silorane resin composite with no surface treatment

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	11.989	18.7	0.001	19659.396	adhesive
1	2	14.873	23.2	0.001	29926.384	adhesive
1	3	18.003	28.1	0.001	29971.736	adhesive
1	4	23.974	37.5	0.001	30167.574	cohesive
1	5	24.163	37.8	0.001	35229.828	adhesive
1	6	21.012	32.8	0.001	28346.456	cohesive
1	7	16.191	25.3	0.001	25860.259	adhesive
1	8	21.285	33.3	0.001	27705.852	adhesive
1	9	25.219	39.4	0.001	26987.274	adhesive
2	1	38.002	59.4	0.006	21959.415	adhesive
2	2	30.998	48.4	0.002	29255.643	adhesive
2	3	31.196	48.7	0.003	20135.514	adhesive
2	4	31.647	49.4	0.002	27290.709	adhesive
2	5	22.926	35.8	0.001	28295.338	adhesive
2	6	31.366	49.0	0.002	26106.402	cohesive
2	7	37.387	58.4	0.003	23919.905	adhesive
2	8	34.834	54.4	0.003	26736.131	adhesive
2	9	9.220	14.4	0.001	21205.412	cohesive
3	1	20.587	32.2	0.001	24495.529	adhesive
3	2	17.123	26.8	0.001	25128.480	adhesive
3	3	25.755	40.2	0.001	27875.945	adhesive
3	4	28.100	43.9	0.002	27256.718	adhesive
3	5	23.856	37.3	0.002	24287.606	adhesive
3	6	14.649	22.9	0.001	23628.253	adhesive
3	7	28.594	44.7	0.002	24736.240	adhesive
3	8	15.077	23.6	0.001	25854.580	adhesive
3	9	16.393	25.6	0.001	25045.739	adhesive
4	1	37.702	58.9	0.003	25969.657	cohesive
4	2	24.850	38.8	0.001	26678.862	adhesive
4	3	27.395	42.8	0.002	30668.317	adhesive
4	4	26.881	42.0	0.002	31018.868	adhesive
4	5	28.207	44.1	0.002	23960.195	adhesive
4	6	25.472	39.8	0.001	31885.178	adhesive
4	7	35.375	55.3	0.002	29458.173	adhesive
4	8	36.666	57.3	0.002	32029.385	adhesive
4	9	34.250	53.5	0.002	28744.256	adhesive

Table 5: Data from group 1S: Silorane resin composite repaired with silorane resin composite with no surface treatment (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	34.622	54.1	0.003	22770.473	adhesive
5	2	19.884	31.1	0.002	23490.611	adhesive
5	3	23.308	36.4	0.002	21869.225	adhesive
5	4	28.058	43.8	0.002	27343.573	adhesive
5	5	32.215	50.3	0.003	24186.103	cohesive
5	6	16.852	26.3	0.001	23301.919	adhesive
5	7	19.905	31.1	0.001	23620.430	adhesive
5	8	18.323	28.6	0.001	26711.591	adhesive
5	9	24.431	38.2	0.002	26684.649	cohesive
6	1	28.846	45.1	0.003	22692.533	adhesive
6	2	20.672	32.3	0.001	30029.849	adhesive
6	3	8.373	13.1	0.000	24410.638	adhesive
6	4	21.709	33.9	0.001	29833.679	adhesive
6	5	17.632	27.5	0.001	25165.293	adhesive
6	6	13.101	20.5	0.001	26729.094	adhesive
6	7	17.825	27.9	0.001	29920.966	adhesive
6	8	28.552	44.6	0.002	25174.640	adhesive
6	9	26.150	40.9	0.002	23636.886	adhesive
7	1	22.638	35.4	0.002	22613.657	adhesive
7	2	16.615	26.0	0.001	25783.128	adhesive
7	3	33.004	51.6	0.002	28551.839	cohesive
7	4	27.388	42.8	0.002	27975.199	adhesive
7	5	24.698	38.6	0.001	27440.270	cohesive
7	6	26.378	41.2	0.002	25758.438	adhesive
7	7	28.374	44.3	0.001	34185.827	adhesive
7	8	20.722	32.4	0.001	26023.292	adhesive
7	9	16.728	26.1	0.001	20396.128	adhesive
8	1	17.679	27.6	0.001	31290.071	adhesive
8	2	20.299	31.7	0.001	29597.517	adhesive
8	3	30.724	48.0	0.002	33763.649	adhesive
8	4	37.928	59.3	0.002	28915.115	adhesive
8	5	24.347	38.0	0.001	28037.364	adhesive
8	6	25.917	40.5	0.002	27283.453	adhesive
8	7	31.199	48.7	0.002	30847.766	adhesive
8	8	24.515	38.3	0.002	25770.824	cohesive
8	9	23.337	36.5	0.001	25602.492	adhesive

Table 6: Data from group 1S: Silorane resin composite repaired with silorane resin composite with no surface treatment (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	36.763	57.4	0.003	29182.010	adhesive
9	2	29.723	46.4	0.002	26059.249	cohesive
9	3	19.573	30.6	0.001	28767.687	adhesive
9	4	13.578	21.2	0.001	31386.580	adhesive
9	5	17.374	27.1	0.001	30082.468	adhesive
9	6	42.742	66.8	0.002	31779.876	adhesive
9	7	35.356	55.2	0.002	32237.415	adhesive
9	8	19.308	30.2	0.001	28560.245	adhesive
9	9	13.422	21.0	0.001	32499.874	adhesive
10	1	16.627	26.0	0.001	29886.013	adhesive
10	2	9.787	15.3	0.000	37870.804	adhesive
10	3	23.614	36.9	0.001	30480.967	adhesive
10	4	12.742	19.9	0.001	34887.992	adhesive
10	5	13.345	20.9	0.001	30668.287	adhesive
10	6	19.027	29.7	0.001	31133.323	adhesive
10	7	21.196	33.1	0.001	27227.316	adhesive
10	8	22.587	35.3	0.001	35329.910	adhesive
10	9	17.710	27.7	0.001	28228.897	adhesive
11	1	19.315	30.2	0.001	29517.663	adhesive
11	2	23.793	37.2	0.001	28309.234	adhesive
11	3	10.819	16.9	0.001	23426.764	adhesive
11	4	19.563	30.6	0.001	32477.888	adhesive
11	5	18.099	28.0	0.001	28336.062	adhesive
11	6	28.198	44.1	0.002	29063.996	adhesive
11	7	24.947	39.0	0.001	33409.922	adhesive
11	8	30.048	46.9	0.002	28737.232	adhesive
11	9	23.577	36.8	0.001	30030.615	adhesive
12	1	26.140	40.8	0.001	30523.525	adhesive
12	2	22.731	35.5	0.001	29461.368	adhesive
12	3	20.532	32.1	0.001	30355.074	cohesive
12	4	28.708	44.9	0.001	32576.134	adhesive
12	5	41.692	65.1	0.002	33881.339	adhesive
12	6	37.151	58.0	0.003	24881.536	cohesive
12	7	19.623	30.7	0.001	28431.382	cohesive
12	8	14.303	22.3	0.001	22124.951	adhesive
12	9	15.379	19.0	0.001	18063.326	adhesive

Table 7: Data from group 2S: Silorane resin composite repaired with silorane resin composite with acid etching

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	15.733	24.6	0.001	27614.081	adhesive
1	2	7.381	11.5	0.001	20223.570	adhesive
1	3	23.163	36.2	0.001	28138.188	adhesive
1	4	22.511	35.2	0.001	23045.319	adhesive
1	5	18.438	28.8	0.001	28089.832	cohesive
1	6	14.626	22.9	0.001	28392.230	adhesive
1	7	19.822	31.0	0.001	30917.757	adhesive
1	8	25.933	40.5	0.001	30045.964	adhesive
1	9	22.459	35.1	0.001	35921.043	adhesive
2	1	43.440	67.9	0.002	31259.980	cohesive
2	2	36.109	56.4	0.002	31987.463	adhesive
2	3	42.597	66.6	0.002	28775.691	cohesive
2	4	41.983	65.6	0.002	32421.470	cohesive
2	5	6.438	10.1	0.001	18808.517	adhesive
2	6	39.441	61.6	0.002	36620.244	adhesive
2	7	11.481	17.9	0.001	32364.161	mixed
2	8	4.367	6.8	0.000	27091.606	adhesive
2	9	21.575	33.7	0.001	32405.511	adhesive
3	1	24.557	38.4	0.001	41836.065	adhesive
3	2	18.239	28.5	0.001	31604.418	adhesive
3	3	23.703	37.0	0.002	25355.978	adhesive
3	4	21.719	33.9	0.001	27334.815	adhesive
3	5	17.701	27.7	0.001	30431.502	adhesive
3	6	12.909	20.2	0.001	23699.294	adhesive
3	7	19.386	30.3	0.001	33693.421	adhesive
3	8	17.319	27.1	0.001	33032.421	adhesive
3	9	24.130	37.7	0.001	34295.089	cohesive
4	1	30.526	47.7	0.002	33622.266	cohesive
4	2	11.756	18.4	0.001	21057.026	adhesive
4	3	29.696	46.4	0.002	26366.834	cohesive
4	4	38.191	59.7	0.003	28954.437	adhesive
4	5	26.278	41.1	0.001	30616.120	adhesive
4	6	44.905	70.2	0.002	31218.658	cohesive
4	7	34.599	54.1	0.003	20604.182	cohesive
4	8	31.864	49.8	0.001	35257.242	cohesive
4	9	46.758	73.1	0.002	35084.445	adhesive

Table 8: Data from group 2S: Silorane resin composite repaired with silorane resin composite with acid etching (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	20.817	32.5	0.001	36999.004	adhesive
5	2	15.329	24.0	0.001	34116.833	cohesive
5	3	37.766	59.0	0.002	31372.650	adhesive
5	4	7.753	12.1	0.000	27381.601	adhesive
5	5	25.585	40.0	0.001	33505.729	adhesive
5	6	37.770	59.0	0.002	35947.473	adhesive
5	7	27.437	42.9	0.001	29005.709	adhesive
5	8	29.305	45.8	0.002	26644.197	adhesive
5	9	10.324	16.1	0.001	29139.177	adhesive
6	1	14.177	22.2	0.001	35498.679	adhesive
6	2	27.282	42.6	0.001	35149.681	cohesive
6	3	28.076	43.9	0.001	40679.402	cohesive
6	4	36.575	57.1	0.003	29193.923	cohesive
6	5	44.063	68.8	0.002	32533.333	cohesive
6	6	16.210	25.3	0.001	34487.570	adhesive
6	7	44.525	69.6	0.002	40593.020	adhesive
6	8	32.528	50.8	0.002	28889.773	adhesive
6	9	12.942	20.2	0.001	24425.997	adhesive
7	1	10.111	15.8	0.001	23035.743	adhesive
7	2	2.518	3.9	0.000	22677.646	adhesive
7	3	7.456	11.7	0.000	25408.254	adhesive
7	4	10.588	16.5	0.001	29255.949	adhesive
7	5	25.460	39.8	0.001	33983.089	adhesive
7	6	24.989	39.0	0.002	23208.424	cohesive
7	7	5.616	8.8	0.000	21780.870	adhesive
7	8	13.025	20.4	0.001	32850.479	adhesive
7	9	14.659	22.9	0.001	20432.433	adhesive
8	1	38.367	59.9	0.002	28117.855	adhesive
8	2	35.473	55.4	0.002	28381.395	adhesive
8	3	22.791	35.6	0.001	26079.993	adhesive
8	4	38.220	59.7	0.003	29360.417	adhesive
8	5	34.049	53.2	0.002	35109.704	cohesive
8	6	39.333	61.5	0.002	32210.411	adhesive
8	7	35.193	55.0	0.002	35592.963	cohesive
8	8	37.481	58.6	0.002	28173.373	adhesive
8	9	40.211	62.8	0.002	27055.937	adhesive

Table 9: Data from group 2S: Silorane resin composite repaired with silorane resin composite with acid etching (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	37.171	58.1	0.002	26879.232	adhesive
9	2	23.927	37.4	0.001	25980.636	adhesive
9	3	33.141	51.8	0.002	29709.371	adhesive
9	4	27.011	42.2	0.002	29292.228	adhesive
9	5	33.120	51.8	0.002	34838.038	adhesive
9	6	29.723	46.4	0.002	31824.458	cohesive
9	7	27.514	43.0	0.001	36116.358	cohesive
9	8	26.990	42.2	0.001	31485.625	adhesive
9	9	17.401	27.2	0.002	16031.791	adhesive
10	1	21.493	33.6	0.002	20043.867	adhesive
10	2	9.024	14.1	0.001	17937.625	adhesive
10	3	4.491	7.0	0.000	20960.449	adhesive
10	4	10.437	16.3	0.001	25162.052	adhesive
10	5	10.239	16.0	0.001	21659.648	adhesive
10	6	11.689	18.3	0.001	26998.773	adhesive
10	7	2.463	3.8	0.000	16649.758	adhesive
10	8	24.996	39.1	0.002	27042.137	adhesive
10	9	28.893	45.1	0.002	28203.153	adhesive
11	1	13.478	21.1	0.001	17490.721	adhesive
11	2	16.927	26.4	0.001	19401.239	adhesive
11	3	9.985	15.6	0.001	21654.990	adhesive
11	4	34.333	53.6	0.002	21720.027	adhesive
11	5	10.337	16.2	0.001	20219.053	adhesive
11	6	31.147	48.7	0.002	32008.851	adhesive
11	7	24.574	38.4	0.001	26123.725	adhesive
11	8	37.824	59.1	0.002	32236.612	adhesive
11	9	41.118	64.2	0.002	29761.192	cohesive
12	1	7.448	11.6	0.001	21338.014	adhesive
12	2	19.186	30.0	0.001	30755.183	adhesive
12	3	8.499	13.3	0.001	19915.417	adhesive
12	4	42.010	65.6	0.003	2332.314	adhesive
12	5	6.499	10.2	0.000	23266.718	adhesive
12	6	29.051	45.4	0.002	26359.642	adhesive
12	7	35.965	56.2	0.002	27729.092	adhesive
12	8	3.889	6.1	0.000	14336.514	adhesive
12	9	28.069	43.9	0.002	27152.893	adhesive

Table 10: Data from group 3S: Silorane resin composite repaired with silorane resin composite with sandblasting

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	23.517	36.7	0.001	30858.069	adhesive
1	2	27.345	42.7	0.002	30445.493	cohesive
1	3	35.317	55.2	0.001	40189.312	adhesive
1	4	26.479	41.4	0.001	42648.595	adhesive
1	5	27.216	42.5	0.002	27898.710	adhesive
1	6	36.188	56.5	0.002	37459.552	adhesive
1	7	30.243	47.3	0.002	33641.682	cohesive
1	8	37.724	58.9	0.002	34230.782	not break
1	9	20.145	31.5	0.001	32994.525	adhesive
2	1	29.417	46.0	0.001	40745.416	cohesive
2	2	30.128	47.1	0.002	31037.728	adhesive
2	3	32.666	51.0	0.003	28677.105	not break
2	4	26.514	41.4	0.001	39483.118	adhesive
2	5	28.950	45.2	0.001	48364.487	adhesive
2	6	42.647	66.6	0.002	41976.177	adhesive
2	7	24.553	38.4	0.002	36197.538	cohesive
2	8	11.517	18.0	0.001	29307.636	cohesive
2	9	38.899	60.8	0.002	33966.539	adhesive
3	1	36.217	56.6	0.002	36676.968	adhesive
3	2	32.616	51.0	0.001	42045.434	adhesive
3	3	35.470	55.4	0.002	32261.808	adhesive
3	4	32.985	51.5	0.002	37654.138	cohesive
3	5	19.716	30.8	0.001	43433.660	cohesive
3	6	41.449	64.8	0.002	47055.851	adhesive
3	7	39.666	62.0	0.002	43242.771	cohesive
3	8	40.995	64.1	0.002	32448.595	mixed
3	9	31.000	48.4	0.001	31605.589	mixed
4	1	35.979	56.2	0.002	28677.639	adhesive
4	2	32.748	51.2	0.002	39383.552	cohesive
4	3	32.987	51.5	0.002	34239.934	cohesive
4	4	27.295	42.6	0.001	31374.372	adhesive
4	5	33.715	52.7	0.001	38617.090	adhesive
4	6	31.482	49.2	0.001	41402.010	adhesive
4	7	37.373	58.4	0.002	40022.149	adhesive
4	8	35.763	55.9	0.001	46509.045	adhesive
4	9	36.254	56.6	0.003	29924.713	adhesive

Table 11: Data from group 3S: Silorane resin composite repaired with silorane resin composite with sandblasting (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	40.086	62.6	0.002	32715.982	adhesive
5	2	24.606	38.4	0.003	27539.933	adhesive
5	3	33.855	52.9	0.002	37866.323	adhesive
5	4	41.311	64.5	0.002	47283.473	adhesive
5	5	32.290	50.5	0.002	28212.589	cohesive
5	6	40.147	62.7	0.002	35290.518	adhesive
5	7	36.954	57.7	0.002	43668.578	cohesive
5	8	34.004	53.1	0.002	33778.560	adhesive
5	9	32.931	51.5	0.001	44576.529	adhesive
6	1	27.805	43.4	0.001	33128.995	adhesive
6	2	26.981	42.2	0.002	26935.544	adhesive
6	3	28.976	45.3	0.001	47710.378	adhesive
6	4	32.272	50.4	0.001	43295.182	adhesive
6	5	34.885	54.5	0.001	45792.247	adhesive
6	6	15.796	24.7	0.001	30424.443	adhesive
6	7	25.078	39.2	0.001	45852.035	adhesive
6	8	21.311	33.3	0.001	49394.619	adhesive
6	9	42.022	65.7	0.001	55476.906	adhesive
7	1	32.853	51.3	0.001	42270.597	adhesive
7	2	30.254	47.3	0.002	34396.031	cohesive
7	3	33.523	52.4	0.002	35719.126	adhesive
7	4	36.337	56.8	0.002	36622.669	cohesive
7	5	34.979	54.7	0.002	38788.749	cohesive
7	6	26.161	40.9	0.002	38539.625	cohesive
7	7	40.960	64.0	0.002	31328.615	adhesive
7	8	37.469	58.5	0.002	32995.291	adhesive
7	9	57.586	90.0	0.002	52443.774	adhesive
8	1	35.675	55.7	0.001	44511.882	adhesive
8	2	28.063	43.8	0.001	32207.913	cohesive
8	3	35.995	56.2	0.002	36629.976	adhesive
8	4	34.692	54.2	0.001	42665.555	adhesive
8	5	25.100	39.2	0.001	47506.722	adhesive
8	6	34.922	54.6	0.002	39022.520	adhesive
8	7	37.220	58.2	0.002	36237.207	adhesive
8	8	33.255	52.0	0.002	31499.412	adhesive
8	9	35.849	56.0	0.001	42293.733	adhesive

Table 12: Data from group 3S: Silorane resin composite repaired with silorane resin composite with sandblasting (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	36.975	57.8	0.001	42501.370	cohesive
9	2	43.145	67.4	0.002	42252.996	adhesive
9	3	35.080	54.8	0.002	32535.574	cohesive
9	4	28.726	44.9	0.001	37162.395	adhesive
9	5	35.395	55.3	0.001	44570.276	cohesive
9	6	29.821	46.6	0.001	43990.585	adhesive
9	7	35.724	55.8	0.002	35956.554	adhesive
9	8	38.599	60.3	0.002	40545.096	adhesive
9	9	40.001	62.5	0.003	32992.707	adhesive
10	1	25.607	40.0	0.001	34277.255	adhesive
10	2	21.569	33.7	0.001	32862.854	adhesive
10	3	30.601	47.8	0.001	40862.967	cohesive
10	4	23.147	36.2	0.001	28875.102	adhesive
10	5	27.918	43.6	0.001	37811.586	cohesive
10	6	26.866	42.0	0.001	38848.498	adhesive
10	7	14.111	22.0	0.001	20285.137	adhesive
10	8	23.712	37.0	0.001	34013.740	adhesive
10	9	24.826	38.8	0.001	38454.532	adhesive
11	1	36.816	57.5	0.002	33350.261	adhesive
11	2	31.685	49.5	0.002	29348.646	adhesive
11	3	37.357	58.4	0.002	33276.942	cohesive
11	4	40.092	62.6	0.002	39697.571	adhesive
11	5	38.470	60.1	0.002	29345.906	adhesive
11	6	26.670	41.7	0.001	41831.118	adhesive
11	7	38.327	59.9	0.001	47906.840	adhesive
11	8	31.304	48.9	0.002	35052.329	adhesive
11	9	32.456	50.7	0.001	44838.573	cohesive
12	1	15.094	23.6	0.001	25737.719	cohesive
12	2	32.780	51.2	0.002	31558.157	adhesive
12	3	25.796	40.3	0.001	36815.120	adhesive
12	4	33.805	52.8	0.002	42324.595	adhesive
12	5	31.699	49.5	0.001	38835.037	adhesive
12	6	30.891	48.3	0.002	34016.666	adhesive
12	7	28.245	44.1	0.001	34912.286	adhesive
12	8	30.329	47.4	0.001	36748.657	cohesive
12	9	39.005	60.9	0.002	37403.810	adhesive

Table 13: Data from group 4S: Silorane resin composite repaired with silorane resin composite with abrasion

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	18.727	29.3	0.001	34881.088	adhesive
1	2	35.615	55.6	0.002	31013.263	adhesive
1	3	28.056	43.8	0.001	35510.973	adhesive
1	4	18.180	28.4	0.001	37256.245	adhesive
1	5	41.134	64.3	0.002	40272.897	adhesive
1	6	30.119	47.1	0.001	34034.782	adhesive
1	7	22.339	34.9	0.002	23595.446	adhesive
1	8	18.049	28.2	0.001	17741.127	adhesive
1	9	25.284	39.5	0.001	28251.527	adhesive
2	1	26.028	40.7	0.001	38038.917	adhesive
2	2	19.410	30.3	0.001	32748.702	adhesive
2	3	25.944	40.5	0.001	36165.272	adhesive
2	4	23.035	36.0	0.001	38045.704	adhesive
2	5	30.282	47.3	0.002	29807.272	adhesive
2	6	29.948	46.8	0.001	38562.353	adhesive
2	7	17.248	27.0	0.001	34268.458	adhesive
2	8	18.885	29.5	0.001	24792.765	adhesive
2	9	19.060	29.8	0.001	19603.516	adhesive
3	1	27.353	42.7	0.001	35800.196	adhesive
3	2	16.667	26.0	0.001	30516.449	adhesive
3	3	22.440	35.1	0.001	33745.179	cohesive
3	4	28.677	44.8	0.002	38874.407	adhesive
3	5	19.158	29.9	0.001	37551.528	adhesive
3	6	13.880	21.7	0.001	36740.561	adhesive
3	7	23.998	37.5	0.001	36670.504	cohesive
3	8	27.159	42.4	0.002	19564.666	adhesive
3	9	17.819	27.8	0.001	26868.475	adhesive
4	1	12.534	19.6	0.001	32321.140	adhesive
4	2	26.804	41.9	0.001	31078.653	adhesive
4	3	28.419	44.4	0.001	38586.612	adhesive
4	4	32.178	50.3	0.001	36534.632	adhesive
4	5	28.003	43.8	0.001	35257.087	adhesive
4	6	29.585	46.2	0.002	26797.881	adhesive
4	7	19.221	30.0	0.001	40072.384	adhesive
4	8	37.980	59.3	0.002	35958.982	adhesive
4	9	33.396	52.2	0.001	45078.355	adhesive

Table 14: Data from group 4S: Silorane resin composite repaired with silorane resin composite with abrasion (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	12.167	19.0	0.001	20213.849	adhesive
5	2	11.635	18.2	0.000	43874.558	adhesive
5	3	26.938	42.1	0.001	35060.369	adhesive
5	4	24.308	38.0	0.001	41068.163	adhesive
5	5	16.708	26.0	0.001	27262.318	adhesive
5	6	7.984	12.5	0.000	46319.445	adhesive
5	7	29.980	46.8	0.001	43858.808	adhesive
5	8	35.065	54.8	0.002	34218.638	adhesive
5	9	31.335	49.0	0.001	41188.384	adhesive
6	1	24.194	37.8	0.001	37243.256	adhesive
6	2	7.629	11.9	0.000	35474.991	adhesive
6	3	19.252	30.1	0.001	20853.269	adhesive
6	4	36.223	56.6	0.002	34654.204	adhesive
6	5	23.239	36.3	0.001	33271.194	cohesive
6	6	34.064	53.2	0.001	38962.819	adhesive
6	7	18.621	29.1	0.001	37452.100	adhesive
6	8	27.364	42.8	0.001	35014.788	adhesive
6	9	23.512	36.7	0.001	35643.820	adhesive
7	1	35.014	54.7	0.002	30653.726	adhesive
7	2	35.161	54.9	0.002	39626.783	adhesive
7	3	23.989	37.5	0.001	28919.867	adhesive
7	4	29.928	46.8	0.001	33474.886	adhesive
7	5	22.012	34.4	0.001	38946.123	adhesive
7	6	21.896	34.2	0.001	32615.506	adhesive
7	7	33.433	52.2	0.001	45334.708	adhesive
7	8	11.502	18.0	0.002	19889.992	adhesive
7	9	25.633	40.1	0.001	38178.315	adhesive
8	1	12.480	19.5	0.001	29216.659	adhesive
8	2	35.235	55.1	0.002	29558.265	adhesive
8	3	32.149	50.2	0.002	33062.749	adhesive
8	4	22.730	35.5	0.001	35415.672	adhesive
8	5	37.774	59.0	0.002	39093.286	adhesive
8	6	31.807	49.7	0.002	27844.848	adhesive
8	7	23.762	37.1	0.001	32921.940	adhesive
8	8	37.159	58.1	0.002	30503.151	adhesive
8	9	12.794	20.0	0.001	35093.951	adhesive

Table 15: Data from group 4S: Silorane resin composite repaired with silorane resin composite with abrasion (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	18.711	29.2	0.001	37267.238	adhesive
9	2	26.596	41.6	0.001	27602.341	adhesive
9	3	24.187	37.8	0.001	38163.698	adhesive
9	4	25.803	40.3	0.001	31001.247	adhesive
9	5	18.554	29.0	0.001	36857.727	adhesive
9	6	20.148	31.5	0.001	33466.796	adhesive
9	7	25.424	39.7	0.001	28159.824	adhesive
9	8	39.095	61.1	0.002	32932.259	adhesive
9	9	26.546	41.5	0.001	32369.905	adhesive
10	1	21.020	32.8	0.001	28765.417	adhesive
10	2	16.158	25.2	0.001	30053.582	adhesive
10	3	16.529	25.8	0.001	25504.984	adhesive
10	4	33.053	51.6	0.001	36437.573	adhesive
10	5	31.867	49.8	0.002	26418.897	adhesive
10	6	35.956	56.2	0.002	44206.732	adhesive
10	7	30.736	48.0	0.001	38462.722	adhesive
10	8	32.523	50.8	0.002	28548.634	adhesive
10	9	20.229	31.6	0.001	33806.494	adhesive
11	1	35.056	54.8	0.002	26504.270	adhesive
11	2	13.179	20.6	0.001	33038.784	adhesive
11	3	23.282	36.4	0.001	38420.645	adhesive
11	4	30.456	47.6	0.001	27130.490	cohesive
11	5	23.230	36.3	0.001	47135.468	adhesive
11	6	23.951	37.4	0.001	32699.537	adhesive
11	7	33.047	51.6	0.002	28176.107	adhesive
11	8	33.059	51.7	0.001	46425.927	cohesive
11	9	20.120	31.4	0.001	29752.108	adhesive
12	1	24.597	38.4	0.001	32046.971	cohesive
12	2	32.391	50.6	0.002	36171.468	adhesive
12	3	27.640	43.2	0.001	29702.976	adhesive
12	4	21.107	33.0	0.001	37777.724	adhesive
12	5	33.488	52.3	0.002	34707.703	adhesive
12	6	22.226	34.7	0.001	35950.260	adhesive
12	7	21.878	34.2	0.001	33449.774	adhesive
12	8	8.935	14.0	0.000	30170.367	adhesive
12	9	20.243	31.6	0.001	36007.095	adhesive

Table 16: Data from group 1M: Silorane resin composite repaired with methacrylate based resin composite with no surface treatment

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	34.398	53.7	0.002	22436.239	adhesive
1	2	39.156	61.2	0.002	39961.710	adhesive
1	3	36.835	57.6	0.002	40355.347	adhesive
1	4	31.801	49.7	0.001	41843.046	cohesive
1	5	31.801	51.8	0.002	38870.613	adhesive
1	6	31.801	45.5	0.001	44141.313	adhesive
1	7	31.801	34.9	0.001	40529.306	adhesive
1	8	31.801	59.7	0.002	39421.110	cohesive
1	9	31.801	41.6	0.001	39246.495	adhesive
2	1	31.801	59.4	0.002	33430.427	adhesive
2	2	31.801	41.4	0.001	38282.491	adhesive
2	3	31.801	43.1	0.001	36901.824	adhesive
2	4	31.801	62.7	0.002	34292.622	adhesive
2	5	31.801	45.8	0.001	35325.191	cohesive
2	6	31.801	53.3	0.001	45364.117	adhesive
2	7	31.801	59.6	0.002	33301.341	adhesive
2	8	31.801	45.1	0.001	32314.700	adhesive
2	9	31.801	45.2	0.001	42685.970	adhesive
3	1	31.801	58.1	0.002	35866.322	cohesive
3	2	31.801	35.1	0.001	40143.321	adhesive
3	3	31.801	43.3	0.001	34669.227	adhesive
3	4	31.801	43.3	0.001	44855.419	cohesive
3	5	31.801	30.2	0.001	31911.759	adhesive
3	6	31.801	44.1	0.001	41181.447	cohesive
3	7	31.801	13.5	0.000	49084.645	adhesive
3	8	31.801	20.6	0.001	40917.246	adhesive
3	9	31.801	58.0	0.002	38554.045	cohesive
4	1	31.801	26.6	0.001	39433.648	adhesive
4	2	31.801	26.2	0.001	21283.586	adhesive
4	3	31.801	18.3	0.001	29356.597	adhesive
4	4	31.801	28.4	0.001	20955.102	adhesive
4	5	31.801	27.4	0.001	46687.911	adhesive
4	6	31.801	46.2	0.002	23456.977	adhesive
4	7	31.801	36.6	0.001	39743.294	adhesive
4	8	31.801	51.1	0.002	37091.162	adhesive
4	9	31.801	45.2	0.001	40736.837	adhesive

Table 17: Data from group 1M: Silorane resin composite repaired with methacrylate based resin composite with no surface treatment (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	36.416	56.9	0.002	41877.773	not break
5	2	15.628	24.4	0.001	38497.526	adhesive
5	3	27.388	42.8	0.001	28315.210	adhesive
5	4	40.859	63.8	0.002	34096.661	adhesive
5	5	13.205	20.6	0.001	14204.364	adhesive
5	6	30.198	47.2	0.001	35879.459	adhesive
5	7	22.881	35.8	0.001	50325.731	cohesive
5	8	15.918	24.9	0.001	39009.430	cohesive
5	9	27.488	43.0	0.001	35752.262	cohesive
6	1	27.935	43.6	0.001	36565.301	cohesive
6	2	20.241	31.6	0.001	41692.568	adhesive
6	3	29.727	46.4	0.001	35050.274	adhesive
6	4	39.968	62.5	0.002	45097.327	adhesive
6	5	23.478	36.7	0.001	42828.373	adhesive
6	6	23.767	37.1	0.001	39864.060	adhesive
6	7	38.846	60.7	0.002	37529.219	adhesive
6	8	35.253	55.1	0.002	30473.114	adhesive
6	9	25.035	39.1	0.001	29872.734	adhesive
7	1	30.226	47.2	0.001	41738.344	adhesive
7	2	47.320	73.9	0.002	42095.992	adhesive
7	3	7.128	11.1	0.000	29087.522	adhesive
7	4	20.744	32.4	0.001	33988.130	adhesive
7	5	40.724	63.6	0.002	41325.363	adhesive
7	6	35.511	55.5	0.001	41027.656	adhesive
7	7	24.240	37.9	0.001	39619.083	adhesive
7	8	19.534	0.5	0.001	34559.579	adhesive
7	9	36.491	57.0	0.001	39117.427	adhesive
8	1	37.932	59.3	0.002	38855.010	adhesive
8	2	31.876	49.8	0.001	39646.151	cohesive
8	3	20.690	32.3	0.001	35521.217	cohesive
8	4	11.577	18.1	0.000	47262.763	cohesive
8	5	39.787	62.2	0.002	39089.867	adhesive
8	6	30.821	48.2	0.001	42029.193	adhesive
8	7	39.891	62.3	0.002	39786.420	cohesive
8	8	32.951	51.5	0.002	35306.270	cohesive
8	9	19.118	29.9	0.001	32478.659	adhesive

Table 18: Data from group 1M: Silorane resin composite repaired with methacrylate based resin composite with no surface treatment (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	29.325	45.8	0.001	35253.938	adhesive
9	2	12.235	19.1	0.001	27870.290	adhesive
9	3	9.136	14.3	0.000	30860.252	adhesive
9	4	20.967	32.8	0.001	37782.447	adhesive
9	5	15.845	24.8	0.001	31701.568	adhesive
9	6	34.597	54.1	0.001	35866.757	adhesive
9	7	10.045	15.7	0.000	34416.112	adhesive
9	8	32.409	50.6	0.001	35127.508	adhesive
9	9	15.482	24.2	0.001	30908.989	cohesive
10	1	25.796	40.3	0.001	32533.853	cohesive
10	2	11.928	18.6	0.000	40169.006	cohesive
10	3	34.850	54.5	0.002	35100.408	adhesive
10	4	15.964	24.9	0.001	32924.805	adhesive
10	5	26.640	41.6	0.001	53262.022	cohesive
10	6	19.020	29.7	0.001	40931.588	adhesive
10	7	5.302	8.3	0.000	16250.347	adhesive
10	8	37.643	58.8	0.002	38739.040	adhesive
10	9	35.909	56.1	0.002	36633.743	adhesive
11	1	39.125	61.3	0.002	40294.263	adhesive
11	2	10.175	15.9	0.001	22098.485	adhesive
11	3	14.986	23.4	0.001	42942.137	adhesive
11	4	10.995	17.2	0.001	30399.752	adhesive
11	5	29.174	45.6	0.002	32704.479	adhesive
11	6	22.897	35.8	0.002	21594.605	adhesive
11	7	31.913	49.9	0.002	31127.214	adhesive
11	8	33.855	52.9	0.002	35798.166	adhesive
11	9	12.130	19.0	0.001	31128.398	adhesive
12	1	18.526	28.9	0.001	36624.996	adhesive
12	2	29.758	46.5	0.001	45323.520	cohesive
12	3	13.081	20.4	0.001	34420.810	adhesive
12	4	8.529	13.3	0.000	34632.035	adhesive
12	5	28.055	43.8	0.001	34163.892	adhesive
12	6	37.097	58.0	0.002	34936.300	cohesive
12	7	23.273	36.4	0.001	39275.324	cohesive
12	8	30.308	47.4	0.002	40381.180	cohesive
12	9	31.982	50.0	0.001	47765.999	adhesive

Table 19: Data from group 2M: Silorane resin composite repaired with methacrylate based resin composite with acid etching

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	38.805	60.6	0.003	31970.284	adhesive
1	2	37.473	58.6	0.002	37295.899	adhesive
1	3	33.404	52.2	0.001	45865.117	adhesive
1	4	34.319	53.6	0.001	46215.269	adhesive
1	5	37.777	59.0	0.002	38473.351	adhesive
1	6	3.309	52.0	0.001	49780.673	adhesive
1	7	29.444	46.0	0.001	49223.831	adhesive
1	8	34.319	53.6	0.001	39905.564	adhesive
1	9	39.275	61.4	0.002	45211.400	adhesive
2	1	10.608	16.6	0.000	38494.078	adhesive
2	2	18.638	29.1	0.001	41060.977	adhesive
2	3	24.723	38.6	0.001	45671.076	adhesive
2	4	20.621	32.2	0.001	38552.093	cohesive
2	5	22.656	35.4	0.001	37775.055	adhesive
2	6	19.879	31.1	0.001	35182.785	adhesive
2	7	23.798	37.2	0.001	44811.270	adhesive
2	8	8.219	12.8	0.000	30607.964	adhesive
2	9	8.303	13.0	0.000	42723.842	adhesive
3	1	43.582	68.1	0.002	42145.963	adhesive
3	2	7.295	11.4	0.000	44374.217	adhesive
3	3	30.831	48.2	0.001	35693.648	adhesive
3	4	33.130	51.8	0.001	38932.324	cohesive
3	5	14.804	23.1	0.001	47548.361	adhesive
3	6	14.475	22.6	0.001	22083.725	adhesive
3	7	35.158	54.9	0.002	33503.138	adhesive
3	8	25.251	39.5	0.001	39670.860	cohesive
3	9	37.350	58.4	0.002	35299.580	cohesive
4	1	39.822	62.2	0.002	38076.789	adhesive
4	2	38.066	59.5	0.002	37122.516	adhesive
4	3	27.457	42.9	0.001	29908.415	adhesive
4	4	10.036	15.7	0.000	41746.092	adhesive
4	5	33.076	51.7	0.001	38685.877	adhesive
4	6	35.316	55.2	0.002	36216.846	adhesive
4	7	24.414	38.1	0.001	38242.034	cohesive
4	8	40.582	63.4	0.002	37233.017	adhesive
4	9	27.175	42.5	0.001	37512.005	cohesive

Table 20: Data from group 2M: Silorane resin composite repaired with methacrylate based resin composite with acid etching (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	26.248	41.0	0.001	38461.734	adhesive
5	2	42.252	66.0	0.002	41848.269	adhesive
5	3	39.129	61.1	0.001	40664.418	adhesive
5	4	27.729	43.3	0.001	34753.478	adhesive
5	5	40.268	62.9	0.002	40640.086	adhesive
5	6	29.537	46.2	0.001	33774.934	adhesive
5	7	49.603	77.5	0.002	42759.489	adhesive
5	8	29.676	46.4	0.001	43079.348	cohesive
5	9	19.124	29.9	0.001	28911.487	adhesive
6	1	32.629	51.0	0.002	32640.087	cohesive
6	2	12.629	19.7	0.000	48388.363	adhesive
6	3	30.253	47.3	0.001	42916.205	cohesive
6	4	37.637	58.8	0.002	44197.164	adhesive
6	5	32.922	51.4	0.001	50993.865	adhesive
6	6	7.759	12.1	0.000	27717.374	adhesive
6	7	28.940	45.2	0.001	40364.615	cohesive
6	8	16.407	25.6	0.001	37311.366	adhesive
6	9	40.221	62.8	0.002	38885.682	adhesive
7	1	34.372	53.7	0.002	29457.318	adhesive
7	2	22.236	34.7	0.001	39850.926	adhesive
7	3	36.200	56.6	0.002	43335.866	cohesive
7	4	12.747	19.9	0.001	23094.247	adhesive
7	5	24.492	38.3	0.001	47756.153	adhesive
7	6	28.464	44.5	0.001	35809.558	adhesive
7	7	31.445	49.1	0.001	41478.587	adhesive
7	8	34.006	53.1	0.001	42925.937	cohesive
7	9	41.138	64.3	0.002	44887.631	adhesive
8	1	30.211	47.2	0.002	35161.291	adhesive
8	2	38.049	59.5	0.002	35769.991	adhesive
8	3	21.990	34.4	0.001	39997.535	cohesive
8	4	20.164	31.5	0.001	34923.259	adhesive
8	5	35.578	55.6	0.002	37887.635	adhesive
8	6	26.689	41.7	0.001	33966.796	adhesive
8	7	24.141	37.7	0.001	34181.338	adhesive
8	8	32.956	51.5	0.002	31635.478	cohesive
8	9	36.542	57.1	0.002	34573.226	cohesive

Table 21: Data from group 2M: Silorane resin composite repaired with methacrylate based resin composite with acid etching (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	9.038	14.1	0.000	31697.063	adhesive
9	2	24.700	38.6	0.001	30373.708	cohesive
9	3	23.492	36.7	0.001	36449.604	adhesive
9	4	35.228	55.0	0.002	34568.951	adhesive
9	5	6.791	10.6	0.000	41324.877	adhesive
9	6	22.727	35.5	0.001	40495.925	adhesive
9	7	29.500	46.1	0.001	34393.097	adhesive
9	8	33.629	52.5	0.002	31916.489	cohesive
9	9	29.185	45.6	0.002	37163.173	adhesive
10	1	25.366	39.6	0.001	37996.335	adhesive
10	2	39.458	61.7	0.002	41675.991	adhesive
10	3	36.589	57.2	0.001	48985.274	adhesive
10	4	44.242	69.1	0.003	31737.946	adhesive
10	5	28.591	44.7	0.001	43817.409	adhesive
10	6	33.165	51.8	0.002	43790.977	adhesive
10	7	13.295	20.8	0.000	45974.785	adhesive
10	8	28.946	45.2	0.001	33643.816	adhesive
10	9	32.552	50.9	0.001	38356.266	adhesive
11	1	27.623	43.2	0.001	32732.450	cohesive
11	2	37.323	58.3	0.001	40319.196	adhesive
11	3	31.660	49.5	0.001	43246.130	adhesive
11	4	25.814	40.3	0.001	28587.719	adhesive
11	5	36.315	56.7	0.002	38341.083	adhesive
11	6	14.086	22.0	0.001	19107.746	adhesive
11	7	28.355	44.3	0.001	31108.789	cohesive
11	8	25.905	40.5	0.001	39468.132	adhesive
11	9	37.040	57.9	0.002	30612.922	adhesive
12	1	28.543	44.6	0.001	31871.963	adhesive
12	2	19.086	29.8	0.001	36924.039	adhesive
12	3	29.430	46.0	0.001	38111.900	adhesive
12	4	20.800	32.5	0.001	39984.539	adhesive
12	5	14.615	22.8	0.001	37396.147	adhesive
12	6	27.188	42.5	0.001	26002.111	adhesive
12	7	33.380	52.2	0.002	32770.382	adhesive
12	8	28.771	45.0	0.001	37971.429	adhesive
12	9	16.861	26.3	0.001	32650.731	adhesive

Table 22: Data from group 3M: Silorane resin composite repaired with methacrylate based resin composite with sandblasting

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	26.976	42.2	0.002	36297.307	cohesive
1	2	33.738	52.7	0.002	36445.248	adhesive
1	3	30.816	48.2	0.001	35556.235	cohesive
1	4	35.320	55.2	0.002	34885.896	adhesive
1	5	26.583	41.5	0.001	39778.723	cohesive
1	6	27.847	43.5	0.001	38877.269	cohesive
1	7	31.916	49.9	0.001	43138.062	cohesive
1	8	34.670	54.2	0.002	36482.022	adhesive
1	9	21.124	33.0	0.001	33322.035	adhesive
2	1	19.178	30.0	0.001	37142.836	adhesive
2	2	31.733	49.6	0.001	41405.506	cohesive
2	3	29.257	45.7	0.002	33095.525	cohesive
2	4	11.239	17.6	0.000	37782.972	adhesive
2	5	30.579	47.8	0.001	32688.762	adhesive
2	6	25.082	39.2	0.001	36007.776	cohesive
2	7	17.459	27.3	0.001	44188.087	adhesive
2	8	34.881	54.5	0.002	35503.608	adhesive
2	9	18.281	28.6	0.001	30393.899	adhesive
3	1	21.802	34.1	0.001	47201.770	adhesive
3	2	36.154	56.5	0.002	33871.748	cohesive
3	3	35.451	55.4	0.002	31547.643	adhesive
3	4	28.587	44.7	0.001	42539.708	adhesive
3	5	18.259	28.5	0.001	30956.661	adhesive
3	6	23.255	36.3	0.001	31422.537	adhesive
3	7	24.874	38.9	0.001	42369.666	cohesive
3	8	30.485	47.6	0.001	35002.284	cohesive
3	9	32.835	51.3	0.001	46612.224	cohesive
4	1	22.517	35.2	0.001	29188.599	adhesive
4	2	29.369	45.9	0.001	43744.986	adhesive
4	3	28.949	45.2	0.001	43316.066	adhesive
4	4	30.177	47.2	0.001	43915.899	cohesive
4	5	13.249	20.7	0.001	30178.310	adhesive
4	6	27.660	43.2	0.001	42315.581	adhesive
4	7	32.437	50.7	0.002	26918.284	cohesive
4	8	25.017	39.1	0.001	41519.004	adhesive
4	9	38.208	59.7	0.001	44821.987	adhesive

Table 23: Data from group 3M: Silorane resin composite repaired with methacrylate based resin composite with sandblasting (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	41.232	64.4	0.002	38561.653	adhesive
5	2	30.561	47.8	0.001	43929.272	cohesive
5	3	38.484	60.1	0.002	46879.234	cohesive
5	4	37.110	58.0	0.001	43397.376	adhesive
5	5	29.932	46.8	0.002	23527.240	adhesive
5	6	31.674	49.5	0.002	33396.901	adhesive
5	7	39.684	62.0	0.002	40336.780	adhesive
5	8	28.929	45.2	0.001	36889.202	cohesive
5	9	38.223	59.7	0.001	48218.057	cohesive
6	1	37.593	58.7	0.002	39581.483	cohesive
6	2	37.873	59.2	0.002	37717.866	adhesive
6	3	34.304	53.6	0.001	42374.338	cohesive
6	4	35.665	55.7	0.001	42282.239	adhesive
6	5	32.625	51.0	0.001	51007.642	adhesive
6	6	19.363	30.3	0.001	43143.266	adhesive
6	7	21.607	33.8	0.001	47865.643	adhesive
6	8	37.415	58.5	0.002	32464.224	cohesive
6	9	34.026	53.2	0.001	39995.729	adhesive
7	1	32.634	51.0	0.001	42920.996	adhesive
7	2	29.821	46.6	0.001	39147.186	adhesive
7	3	39.051	61.0	0.002	37099.852	adhesive
7	4	31.138	48.7	0.001	41526.619	adhesive
7	5	27.722	43.3	0.001	48315.613	adhesive
7	6	27.315	42.7	0.001	37214.053	cohesive
7	7	38.930	60.8	0.002	32960.038	adhesive
7	8	28.607	44.7	0.001	34692.058	adhesive
7	9	32.922	51.4	0.001	41588.414	adhesive
8	1	31.381	49.0	0.002	43139.154	cohesive
8	2	40.589	63.4	0.002	41404.762	adhesive
8	3	36.473	57.0	0.001	44891.501	adhesive
8	4	13.719	21.4	0.001	34309.651	cohesive
8	5	36.869	57.6	0.001	47334.573	adhesive
8	6	40.509	63.3	0.002	42984.902	adhesive
8	7	40.267	62.9	0.002	32307.182	adhesive
8	8	30.343	47.4	0.002	31992.466	cohesive
8	9	35.594	55.6	0.002	36907.277	cohesive

Table 24: Data from group 3M: Silorane resin composite repaired with methacrylate based resin composite with sandblasting (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	35.808	56.0	0.002	33083.653	adhesive
9	2	26.755	41.8	0.002	43303.813	adhesive
9	3	27.924	43.6	0.001	39892.009	adhesive
9	4	25.534	39.9	0.001	35510.911	adhesive
9	5	33.772	52.8	0.002	38428.292	cohesive
9	6	30.794	48.1	0.001	37912.595	adhesive
9	7	39.900	62.3	0.001	51029.118	adhesive
9	8	35.383	55.3	0.001	40918.455	adhesive
9	9	26.917	42.1	0.002	37657.176	cohesive
10	1	31.803	49.7	0.001	41299.094	adhesive
10	2	30.867	48.2	0.001	58581.740	cohesive
10	3	41.507	64.9	0.002	32806.009	cohesive
10	4	31.015	48.5	0.001	55008.087	adhesive
10	5	33.838	52.9	0.002	36106.184	adhesive
10	6	27.710	43.3	0.001	37983.636	adhesive
10	7	36.016	56.3	0.001	44178.734	adhesive
10	8	28.142	44.0	0.001	44709.475	adhesive
10	9	31.655	49.5	0.002	36374.809	cohesive
11	1	28.579	44.7	0.001	36815.593	cohesive
11	2	28.797	45.0	0.001	38416.749	cohesive
11	3	30.228	47.2	0.001	40308.087	adhesive
11	4	32.509	50.8	0.001	43940.877	adhesive
11	5	36.398	56.9	0.002	36508.943	cohesive
11	6	32.139	50.2	0.001	37134.053	adhesive
11	7	35.115	54.9	0.002	36907.631	adhesive
11	8	34.349	53.7	0.001	41360.948	cohesive
11	9	27.183	42.5	0.001	40345.728	cohesive
12	1	18.326	28.6	0.001	32287.790	adhesive
12	2	30.368	47.5	0.001	37816.752	adhesive
12	3	27.844	43.5	0.001	40346.556	cohesive
12	4	24.814	38.8	0.001	44601.178	cohesive
12	5	29.886	46.7	0.001	37169.608	cohesive
12	6	37.287	58.3	0.001	48171.499	adhesive
12	7	33.573	52.5	0.002	40474.288	adhesive
12	8	27.010	42.2	0.001	35080.930	adhesive
12	9	27.601	43.1	0.001	53354.869	mixed

Table 25: Data from group 4M: Silorane resin composite repaired with methacrylate based resin composite with abrasion

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
1	1	11.443	17.9	0.001	33070.094	adhesive
1	2	11.140	17.4	0.000	35799.506	adhesive
1	3	22.237	34.7	0.001	37119.955	adhesive
1	4	19.453	30.4	0.001	33428.540	adhesive
1	5	13.694	21.4	0.001	32148.323	adhesive
1	6	20.736	32.4	0.001	38949.960	adhesive
1	7	21.934	34.3	0.001	41286.149	adhesive
1	8	26.026	40.7	0.001	33045.189	mixed
1	9	28.681	44.8	0.001	34135.259	adhesive
2	1	29.474	46.1	0.001	43740.181	adhesive
2	2	26.179	40.9	0.002	27521.755	mixed
2	3	28.064	43.8	0.004	27082.979	adhesive
2	4	25.775	40.3	0.001	43532.850	adhesive
2	5	20.460	32.0	0.001	41747.648	cohesive
2	6	18.807	29.4	0.001	44072.607	adhesive
2	7	29.690	46.4	0.001	38405.109	adhesive
2	8	10.803	16.9	0.000	35371.814	adhesive
2	9	12.220	19.1	0.000	49612.315	adhesive
3	1	9.227	14.4	0.000	38363.741	adhesive
3	2	30.151	47.1	0.001	37261.015	adhesive
3	3	29.277	45.7	0.001	41114.433	adhesive
3	4	21.072	32.9	0.001	41458.382	adhesive
3	5	31.443	49.1	0.002	39459.914	adhesive
3	6	32.804	51.3	0.001	44306.056	adhesive
3	7	31.412	49.1	0.001	51805.711	adhesive
3	8	14.424	22.5	0.001	38706.186	adhesive
3	9	27.480	42.9	0.001	41378.872	adhesive
4	1	11.105	17.4	0.001	27828.064	adhesive
4	2	20.687	32.3	0.001	41770.296	adhesive
4	3	26.448	41.3	0.001	33940.708	adhesive
4	4	32.142	50.2	0.001	37353.146	adhesive
4	5	18.340	28.7	0.001	33479.274	mixed
4	6	12.911	20.2	0.001	34217.413	mixed
4	7	29.955	46.8	0.001	41679.117	adhesive
4	8	33.399	52.2	0.002	40643.206	adhesive
4	9	31.428	49.1	0.001	42682.301	adhesive

Table 26: Data from group 4M: Silorane resin composite repaired with methacrylate based resin composite with abrasion (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
5	1	16.781	26.2	0.001	36126.174	adhesive
5	2	11.179	17.5	0.000	40206.321	adhesive
5	3	21.774	34.0	0.001	34813.179	adhesive
5	4	33.525	52.4	0.002	32910.830	adhesive
5	5	25.650	40.1	0.001	42608.050	adhesive
5	6	17.570	27.5	0.001	49631.118	adhesive
5	7	16.134	25.2	0.001	39538.378	adhesive
5	8	24.658	38.5	0.001	42759.828	adhesive
5	9	24.902	38.9	0.001	42955.772	adhesive
6	1	31.595	49.4	0.001	45697.823	adhesive
6	2	27.577	43.1	0.001	39039.109	adhesive
6	3	33.125	51.8	0.002	33785.864	adhesive
6	4	29.143	45.5	0.002	36683.866	adhesive
6	5	27.536	43.0	0.001	41152.051	adhesive
6	6	31.180	48.7	0.001	38211.290	adhesive
6	7	29.169	45.6	0.001	44207.031	adhesive
6	8	23.366	36.5	0.001	37169.921	cohesive
6	9	21.943	34.3	0.002	34328.373	cohesive
7	1	34.263	53.5	0.002	27281.236	adhesive
7	2	12.382	19.3	0.001	37500.371	adhesive
7	3	19.157	29.9	0.001	34968.801	adhesive
7	4	27.338	42.7	0.001	34041.267	adhesive
7	5	29.023	45.3	0.001	33617.498	adhesive
7	6	37.924	59.3	0.002	33235.265	adhesive
7	7	17.508	27.4	0.001	30353.592	adhesive
7	8	19.487	30.4	0.001	35166.281	adhesive
7	9	17.491	27.3	0.001	36981.164	adhesive
8	1	19.331	30.2	0.001	40196.131	adhesive
8	2	25.191	39.4	0.002	24449.446	adhesive
8	3	17.926	28.0	0.001	29787.435	cohesive
8	4	17.839	27.9	0.001	33279.508	mixed
8	5	27.111	42.4	0.001	34827.659	adhesive
8	6	27.151	42.4	0.001	34445.839	adhesive
8	7	17.331	27.1	0.001	24199.892	adhesive
8	8	25.533	39.9	0.002	27684.501	adhesive
8	9	22.683	35.4	0.002	27621.336	cohesive

Table 27: Data from group 4M: Silorane resin composite repaired with methacrylate based resin composite with abrasion (cont.)

Block	Beam	Peak Load	Peak Stress	Strain	Modulus	Failure type
9	1	25.563	39.9	0.002	36278.791	adhesive
9	2	22.967	35.9	0.001	34103.152	adhesive
9	3	35.714	55.8	0.002	31046.680	adhesive
9	4	25.796	40.3	0.001	31815.259	adhesive
9	5	17.786	27.8	0.001	32855.127	adhesive
9	6	23.505	36.7	0.001	33640.440	adhesive
9	7	15.351	24.0	0.001	33700.176	adhesive
9	8	35.748	55.9	0.002	40917.089	adhesive
9	9	27.217	42.5	0.001	36616.188	adhesive
10	1	30.126	47.1	0.001	33777.318	adhesive
10	2	32.007	50.0	0.001	42596.984	adhesive
10	3	34.145	53.4	0.002	35871.186	adhesive
10	4	22.080	34.5	0.001	32050.037	adhesive
10	5	21.559	33.7	0.001	35618.062	adhesive
10	6	28.954	45.2	0.001	42763.857	adhesive
10	7	17.368	27.1	0.001	31561.688	adhesive
10	8	32.470	50.7	0.002	39661.745	adhesive
10	9	20.459	32.0	0.001	50223.531	adhesive
11	1	25.920	40.5	0.001	40971.245	adhesive
11	2	22.869	35.7	0.001	43079.530	adhesive
11	3	27.583	43.1	0.001	35607.965	mixed
11	4	31.034	48.5	0.002	35782.829	adhesive
11	5	23.567	36.8	0.001	27901.552	adhesive
11	6	29.758	46.5	0.002	31004.204	adhesive
11	7	29.600	46.2	0.001	48478.863	adhesive
11	8	16.581	25.9	0.001	25369.186	adhesive
11	9	17.594	27.5	0.001	30068.234	adhesive
12	1	35.468	55.4	0.002	35894.422	adhesive
12	2	23.493	36.7	0.001	43458.103	cohesive
12	3	18.445	28.8	0.001	25993.496	cohesive
12	4	35.353	55.2	0.002	37005.657	adhesive
12	5	24.006	37.5	0.001	42828.326	adhesive
12	6	25.259	39.5	0.001	39490.576	adhesive
12	7	31.776	49.6	0.002	36488.913	adhesive
12	8	28.861	45.1	0.001	39998.063	adhesive
12	9	10.406	16.3	0.001	31549.742	adhesive

Table 28: P-value and comparison for microtensile bond strength and failure mode

Microtensile Peak Stress		Failure Mode	
p-value	**Comparison**	**p-value**	**Comparison**
0.58	1M & 1S	0.10	1M & 1S
0.69	1M & 2M	0.39	1M & 2M.
0.63	1M & 2S	0.71	1M & 2S
0.48	1M & 3M	0.06	1M & 3M
0.33	1M & 3S	0.52	1M & 3S
0.63	1M & 4M	0.08	1M & 4M
0.79	1M & 4S	0.004*	1M < 4S
0.03*	1M < Control		
0.34	1S & 2M	0.33	1S & 2M
0.96	1S & 2S	0.20	1S & 2S
0.21	1S & 3M	0.001*	1S > 3M
0.12	1S & 3S	0.007*	1S > 3S
0.94	1S & 4M	0.84	1S & 4M
0.77	1S & 4S	0.09	1S & 4S
0.006*	1S < Control		
0.38	2M & 2S	0.65	2M & 2S
0.76	2M & 3M	0.001*	2M > 3M
0.55	2M & 3S	0.07	2M & 3S
0.38	2M & 4M	0.27	2M & 4M
0.51	2M & 4S	0.015*	2M < 4S
0.07	2M & Control		
0.24	2S & 3M	0.018*	2S > 3M
0.14	2S & 3S	0.28	2S & 3S
0.99	2S & 4M	0.16	2S & 4M
0.82	2S & 4S	0.009*	2S < 4S
0.008*	2S < Control		
0.77	3M & 3S	0.11	3M & 3S
0.23	3M & 4M	0.001*	3M < 4M
0.33	3M & 4S	0.001*	3M < 4S
0.13	3M & Control		
0.14	3S & 4M	0.006*	3S < 4M
0.21	3S & 4S	0.001*	3S < 4S
0.23	3S & Control		
0.83	4M & 4S	0.13	4M & 4S
0.007*	4M < Control		
0.014*	4S < Control		

* statistically significant difference

ABSTRACT

EFFECT OF SURFACE TREATMENTS ON MICROTENSILE BOND STRENGTH OF REPAIRED AGED SILORANE RESIN COMPOSITE

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Background: A silorane based resin composite, Filtek LS restorative, has been introduced to overcome the polymerization shrinkage of the methacrylate based resin composite. The repair of resin composite may hold clinical advantages. Currently, there is no available information regarding the repair potential of silorane resin composite with either silorane or methacrylate based resin composite. **Objectives:** The purpose of this study was to compare the repaired microtensile bond strength of aged silorane resin composite using different surface treatments and either silorane or methacrylate based resin composite. **Methods:** One hundred and eight silorane resin composite blocks (Filtek LS) were fabricated and aged by thermocycling between 8^{o}C and 48^{o}C (5000 cycles). A control (solid resin composite) and four surface treatment groups (no treatment, acid treatment, aluminum oxide sandblasting and diamond bur abrasion) were tested. Each treatment group was randomly divided in half and repaired with either silorane resin composite (LS adhesive) or methacrylate based resin composite (Filtek Z250/Single Bond Plus). Specimens were 12 blocks and 108 beams per group. After 24 hours in 37^{o}C distilled water, microtensile bond strength testing was performed using a non-trimming technique. Fracture surfaces were examined using an optical microscopy (20X) to determine failure mode. Data was analyzed using Weibull-distribution survival analysis. **Results:** Aluminum oxide sandblasting followed by silorane or methacrylate based resin composite and acid treatment with methacrylate based resin composite provided insignificant differences from the control ($p>0.05$). All other groups were significantly lower than the control. Failure was primarily adhesive in all groups. **Conclusion:** Aluminum oxide sandblasting produced comparable microtensile bond strength compared to the cohesive strength of silorane resin composite. After aluminum oxide sandblasting, aged silorane resin composite can be repaired with either silorane resin composite with LS system adhesive or methacrylate based resin composite with methacrylate based dentin adhesive.

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